NITRATE CONTAMINATION OF GROUNDWATER
IN SOUTHERN RUNNELS COUNTY, TEXAS

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NITRATE CONTAMINATION OF GROUNDWATER
IN SOUTHERN RUNNELS COUNTY, TEXAS

by

CHARLES WIGHTMAN KREITLER, B.A.

THESIS

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PREFACE

The author is indebted to many individuals in Runnels County, especially C. T. Parker, Werner Lange, and Paul Peiper, who facilitated the collection and comprehension of the data for this study.

Thanks are also extended to the Radian Corporation, especially Dr. David C. Jones and Dr. P. E. Hudson for their invaluable advice and help. Appreciation is expressed to the Texas Water Development Board for their generous funding of this study. Without their help, this thesis would never have been possible.

Many thanks go to Richard J. Heil, who studied the groundwater contamination in northern Runnels County.

I am greatly indebted to Dr. L. J. Turk for his invaluable help in interpreting the data and his excellent critical review of this thesis. Considerable help in editing this thesis has been from Dr. Keith Young and Dr. Edward Jonas, and Ron Landers.

And to my loving wife, Berf, thank you for just being there.

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NITRATE CONTAMINATION OF GROUNDWATER

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A B S T R A C T

Nitrate concentrations in the groundwater in southern Runnels County, Texas, ranged from less than 0.5 mg/l to 3,580 mg/l. Only ten percent of the water samples analyzed contained less than the U. S. Public Health Service recommended limit for nitrate in drinking water (45 mg/l). The major sources of nitrate contamination are soils beneath or near barnyards or septic tanks. Average total nitrate concentration in barnyard soils was 26,000 pounds of nitrate per 15 acre-feet, whereas the average total nitrate (NO_3) concentration in cultivated fields and pastures was 4,100 lb. NO_3 / 15 acre-feet and 3,900 lb. NO_3 / 15 acre-feet, respectively.

Nitrates appear to be added to the groundwater by two mechanisms. First, large volumes of water from cattle excrement can enter the aquifers by easy drainage down poorly cased water wells. Second, extensive terracing has caused an appreciable rise in the potentiometric surface with subsequent dissolution of nitrate caliches from the soils by groundwater.

Groundwater flow is restricted to solution cavities and fractures in the limestones. Aquifer tests indicate

transmissivities on the order of 10,000 gpd/ft, and coefficients of storage on the order of 10^{-5}. Numerous poorly cased water wells, unplugged seismic shot holes and abandoned oil wells have interconnected the thin limestone aquifers and have permitted extensive contamination of the aquifer system.

Early improvement of future groundwater quality cannot be expected because of the vast quantities of nitrate still in the barnyard soils. Water importation or desalination may prove economically feasible for human consumption, but not for agricultural needs.

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INTRODUCTION

Objectives and Method of Investigation

The objectives of this investigation were to determine the groundwater hydrology, to delineate the extent of nitrate contamination and to define the possible sources of nitrate in southern Runnels County.

During the summer of 1970 the following types of well data were collected from the farm owners in southern Runnels County: depth of water table, total depth of well, depth of water-bearing strata, well construction, type of pump, kind and quantity of livestock in area, distance and direction from livestock pen or septic tank, and history of oil exploration in the area. Some 128 water samples were collected and analyzed by the U. S. Public Health Service for: SiO_2, Ca, Mg, HCO_3, SO_4, Cl, F, NO_3, total nitrogen cycle and total dissolved solids. Seven samples were analyzed by the U. S. Department of Interior for organic carbon. Plate 1 is an index map showing the locations of the water wells. Two aquifer tests were run to determine the permeability and the coefficient of storage of the limestone aquifers.

The summer of 1971 was spent determining the sources of the nitrates. Forty-seven soils were cored and analyzed for nitrate and chloride. Barnyards, septic tank drainage fields, cultivated fields, pastures, mesquite thickets, seeps, and river terrace deposits were all cored.

Health Aspects of Nitrates

Nitrate in groundwater is a pollutant because of its detrimental health effects. Methemoglobinemia (infant cyanosis or cattle cyanosis) is the only nitrate illness that has been adequately studied.

Methemoglobinemia, the conversion of hemoglobin to methemoglobin in the blood, causes cell asphyxiation. The difference between hemoglobin and methomoglobin is the oxidation state of the iron. Iron in hemoglobin is in the ferrous state, whereas iron in methemoglobin is in the ferric state. Oxygen in the blood is carried by the iron cation. In the hemoglobin molecule, oxygen is easily released from the ferrous iron for cell respiration. In the methemoglobin molecule, oxygen is held tightly by the ferric iron. Oxygen release is prevented and cell respiration is eliminated (Winton, 1970).

Nitrites, not nitrates, cause methemoglobinemia. For methemoglobinemia to occur, there must be a conversion of nitrate to nitrite in the gastrointestinal tract. Because of this necessary conversion not all animals are susceptible to nitrate poisoning. Sheep, cattle, horses, pigs and the young of most mammals, including human infants, are susceptible.

In human infants the necessary conditions for infant cyanosis are low gastric acidity and immature enzyme and hemoglobin development. Methemoglobinemia occurs predominantly in babies less than eight weeks old. Their gastro-intestinal system is a suitable environment for nitrate-reducing bacteria, which exist only within a pH range of 5 to 7. A few months after birth a child's stomach becomes more acidic, in the pH range of 2 to 5, and the nitrate-reducing bacteria are destroyed. This change in acidity does not occur in pigs, cattle or sheep; thus these mammals are susceptible to methemoglobinemia regardless of age.

Susceptibility to nitrate poisoning has also been correlated to infants' hemoglobin type and lack of necessary enzymes. A child is born with 80 percent fetal hemoglobin (hemoglobin F), but within three to four months a child converts most of the hemoglobin F to adult hemoglobin (hemoglobin A). Hemoglobin F is more easily oxidized to methemoglobin than hemoglobin A. Methemoglobin is converted back to hemoglobin by the enzyme diaphorase. This enzyme does not completely develop in an infant until three or four months after birth (Winton, 1970).

Other physiological effects, besides clinical methemoglobinemia, are caused by nitrates. Gruener and Shuval (1970) have shown that continual ingestion of low nitrate concentrations cause chronic subclinical methemoglobinemia. Lijinsky and Epstein (1970), Alam _et al_. (1971), and Asahina *et al.* (1971) suggested that some forms of human cancer may be caused by nitrosamines formed from nitrite and certain amines in cooked food. Livestock develop thyroid problems, rickets, enteritis, arthritis and general poor health from ingesting nitrates (Case, 1970).

The safe level of nitrate in drinking water has not been adequately determined. The United States Public Health Service (Department of Health Education and Welfare) (1962) has set 45 mg/l as the maximum level of nitrates in public drinking water. Other nations have set maximum nitrate levels from 0.5 mg/l to 228 mg/l with no general agreement (Gruener and Shuval, 1970, p. 92). These limits, at best, are based on clinical records of methemoglobinemia in infants. Further research needs to be done on chronic methemoglobinemia, nitrate-induced cancer, and the suitable nitrate concentration limits for these illnesses.

Previous Investigations in Runnels County

The deaths of several cattle in Runnels County in July of 1968 prompted a Texas Water Quality Board study (Report of March 31, 1969) which concluded that the cattle died of nitrate poisoning. On June 23, 1969, another herd of cattle died of nitrate poisoning. As a result of these deaths field investigations were conducted by the Texas Water Development Board. C. T. Parker, Jr., the Runnels County Agent, collected

850 water samples which were analyzed for nitrate by the Texas A and M University Extension Laboratories in Lubbock. The results showed an erratic distribution of nitrate concentrations as high as 2,310 milligrams per liter (mg/l) (Beffort, 1969).

The Texas Board of Water Engineers conducted a reconnaissance study of salt water contamination by oil field operations in Runnels County (Shamburger, 1959). The Texas Railroad Commission also studied the salt water contamination problem in 1968 (Beffort, 1969). Both studies concluded that the oil industry was partially responsible for the high chloride concentrations in the groundwater. Neither of these studies included analyses for nitrate.

Agriculture, Culture and History

The economy of Runnels County is based on the production of cattle, hogs, sheep, chickens, wheat, sorghum and cotton. In 1970 there were 50,000 cattle, 3,600 hogs and 66,000 sheep on the farms, and 27,500 bales of cotton, 513,000 bushels of wheat and 1,672,800 bushels of sorghum were harvested. The total agriculture production was worth 12 million dollars (Texas Department of Agriculture, 1971). In the southern part of the county cattle are kept both in barnyards and pastures for extended periods. Hogs are always confined to pens. There is minimal use of fertilizer and irrigation.

The population is 95 percent rural, with fewer than a thousand people in the hamlets of Rowena and Miles. The population has greatly decreased during the past thirty years. In the 1930's there was an average of one farm per forty acres. Today, there are only a few farms per square mile.

The water supply for the southern part of the county is groundwater, surface water and bottled water. Rowena obtains the only surface water in the southern part of the county from Lake Ballinger. There are no sewage disposal systems other than septic tanks, cesspools or outhouses.

The county was settled initially in the 1840's, when the land was grazed equally by cattle and buffalo. At the turn of the century farmers from eastern Europe settled. As late as 1930 cattle drives followed a branch of the Chisolm Trail through the southern part of the county. Cattle were driven to railheads in San Angelo and Abilene, Texas.

Location and Climate

Runnels County is in west-central Texas, 30 miles east of San Angelo and 30 miles north of Eden (fig. 1). Total area of the county is 1,860 square miles. The area of the southern part of the county included in this study is approximately 500 square miles. The northern boundary of the study area is the Colorado River.

Average annual rainfall is about 22 inches (fig. 2), and the average annual temperature is 65 degrees Fahrenheit.

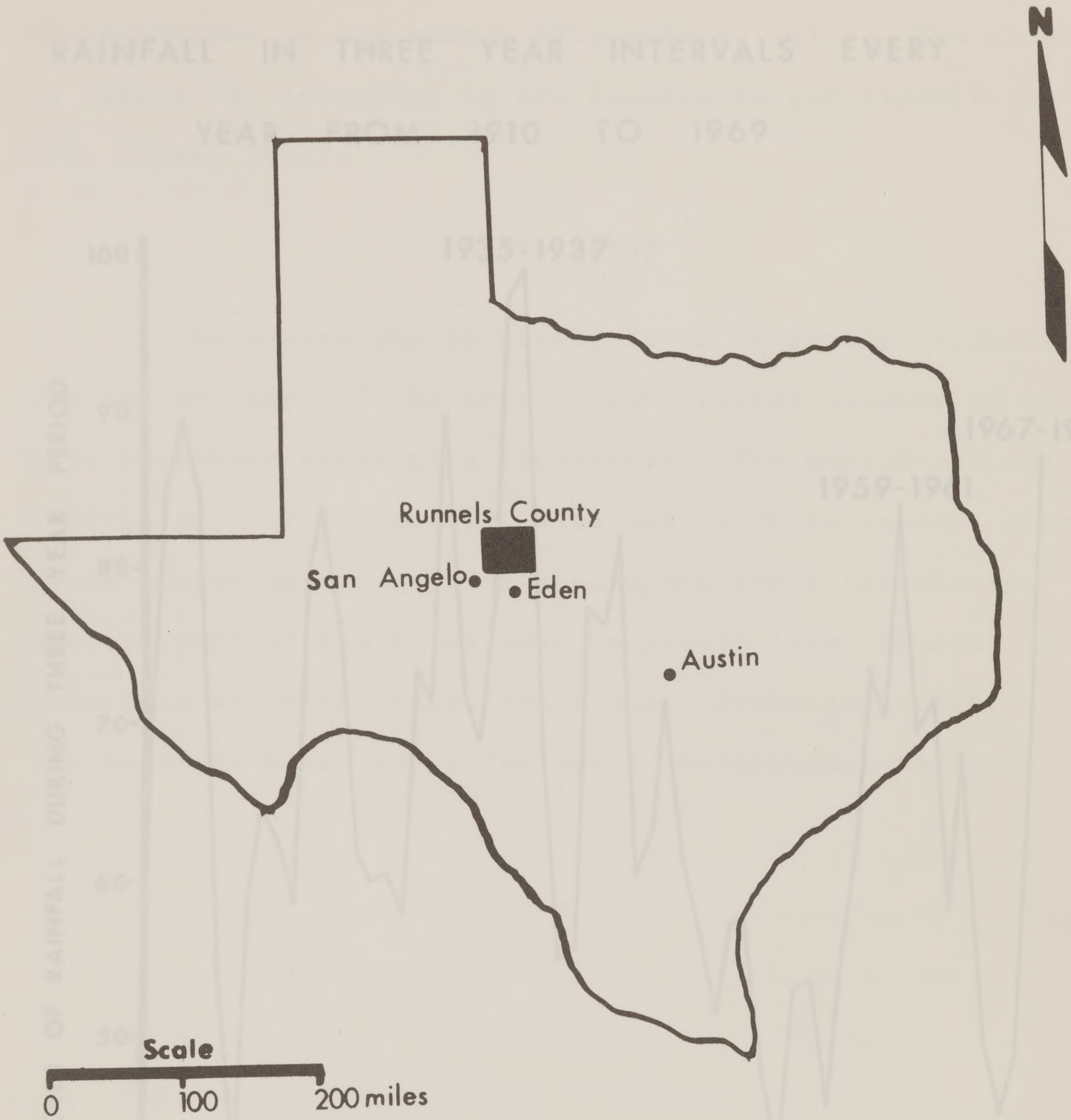


Figure 1. Location of Runnels County, Texas.

RAINFALL IN THREE YEAR INTERVALS EVERY YEAR FROM 1910 TO 1969

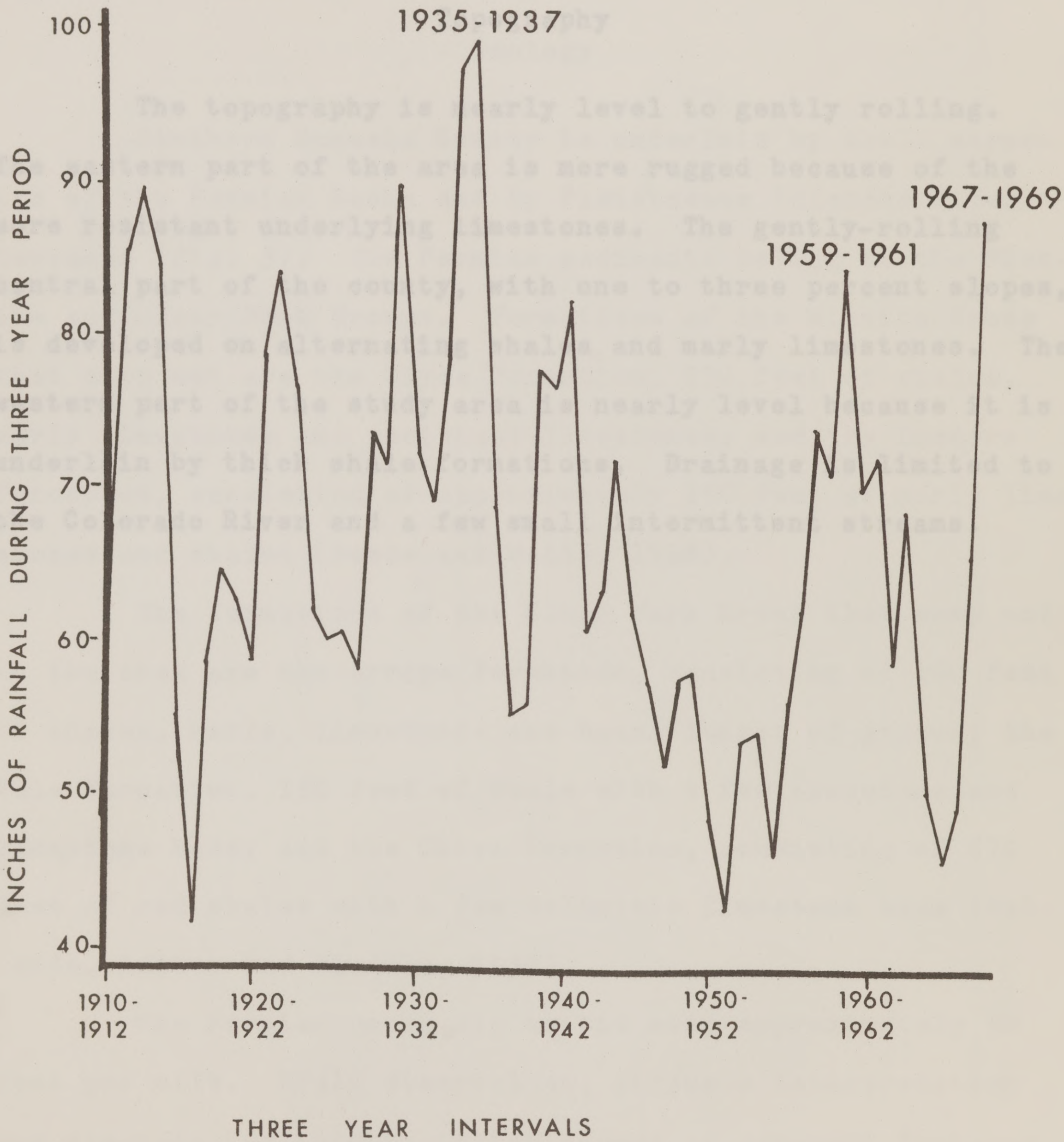


Figure 2

Most of the rainfall occurs during the winter, with sporadic thunderstorms in the summer (Wiedenfeld, 1970). The climate is semi-arid, according to the Koeppen-Geiger classification (Van Riper, 1962).

Topography

The topography is nearly level to gently rolling. The eastern part of the area is more rugged because of the more resistant underlying limestones. The gently-rolling central part of the county, with one to three percent slopes, is developed on alternating shales and marly limestones. The western part of the study area is nearly level because it is underlain by thick shale formations. Drainage is limited to the Colorado River and a few small intermittent streams.

HYDROGEOLOGY

In order to understand the extent of nitrate contamination it was necessary to study the hydrogeology of southern Runnels County.

Geology

Southern Runnels County is underlain by shelf deposits of the Permian Basin and by Pleistocene Colorado River terraces (fig. 3). The Permian sediments belong to the Wichita and Clear Fork Groups. Formations of the Wichita Group that crop out are the Clyde Formation, 530 feet of shales, marly limestones and resistant limestones; and the Lueders Formation, consisting of approximately 190 feet of marly limestones and shales (Beede and Waite, 1918).

The formations of the Clear Fork Group that crop out in the area are the Arroyo Formation, consisting of 260 feet of shales, marls, limestones and basal lenses of gypsum; the Vale Formation, 150 feet of shale with a few sandstone and limestone beds; and the Choza Formation, consisting of 870 feet of red shales with a few dolomitic limestone beds (Sellards, Adkins and Plummer, 1933).

The Permian rocks dip to the west approximately 50 feet per mile. Field observation, airphoto interpretation and electric log interpretation showed no apparent faulting.

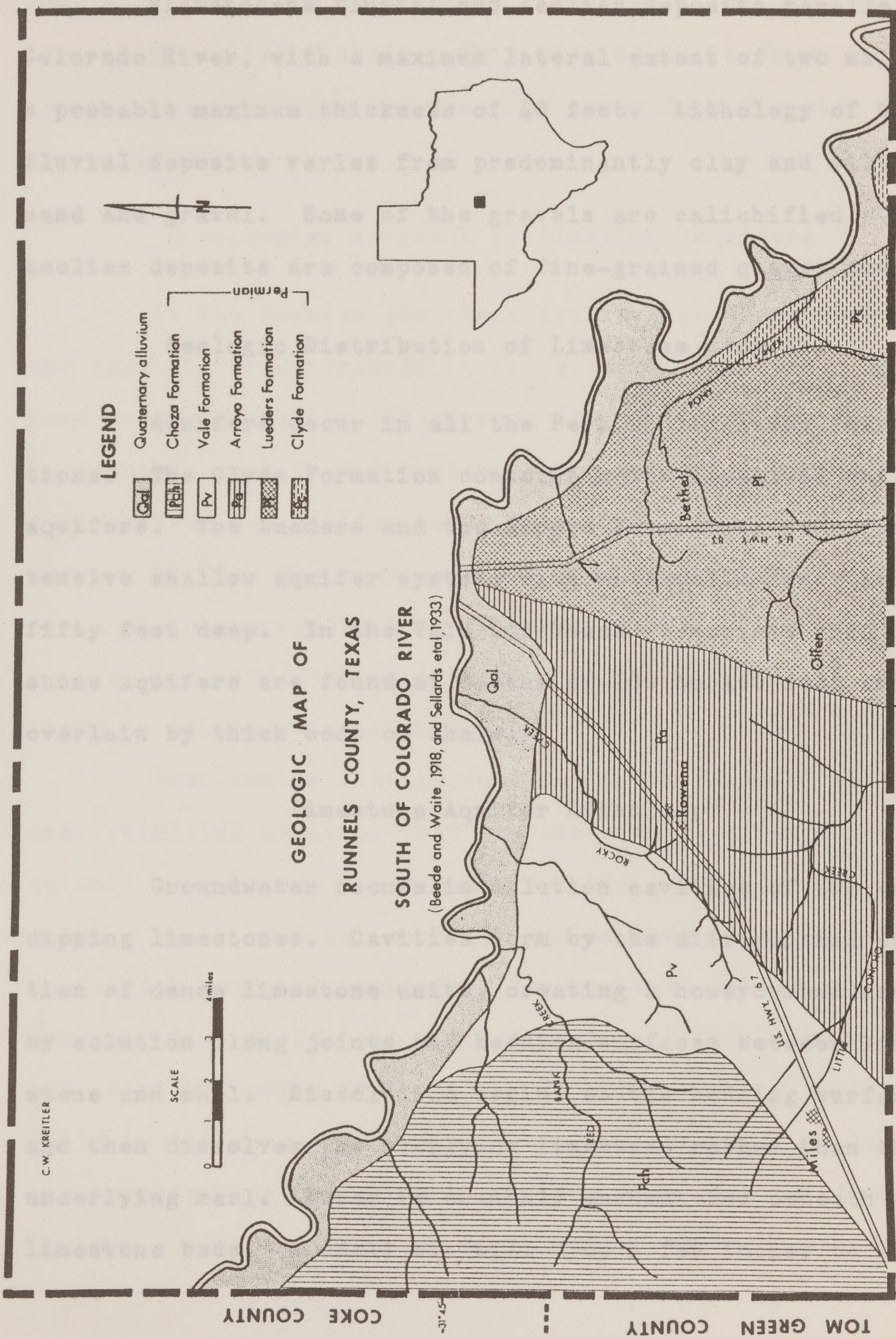

GEOLOGIC MAP OF
RUNNELS COUNTY, TEXAS
SOUTH OF COLORADO RIVER
(Beede and Waite, 1918, and Sellards etal, 1933)
LEGEND
Qal Quaternary alluvium
Pch Choza Formation
Pv Vale Formation
Pa Arroyo Formation
Pl Lueders Formation
Pc Clyde Formation
Permian
N
C.W. KREITLER
SCALE
0 1 2 3 4 miles
COKE COUNTY
TOM GREEN COUNTY
CONCHO COUNTY
-31°45'
100°00'
Qal
Pch
Pv
Pa
Pl
Pc
Miles
Rowena
Bethel
Olfen
U.S. HWY. 67
U.S. HWY. 83
RED BANK CREEK
ROCKY CREEK
LITTLE CONCHO CREEK

Figure 3

Pleistocene fluvial and aeolian deposits parallel the Colorado River, with a maximum lateral extent of two miles and a probable maximum thickness of 40 feet. Lithology of the fluvial deposits varies from predominantly clay and silt to sand and gravel. Some of the gravels are calichified. The aeolian deposits are composed of fine-grained quartz sand.

Geologic Distribution of Limestone Aquifers

Aquifers occur in all the Permian limestone formations. The Clyde Formation contains a few localized shallow aquifers. The Lueders and the Arroyo Formations comprise extensive shallow aquifer systems with most wells less than fifty feet deep. In the Vale and Choza Formations thin limestone aquifers are found at depths of 100 to 150 feet and are overlain by thick beds of shale.

Limestone Aquifer Lithology

Groundwater occurs in solution cavities of the gently-dipping limestones. Cavities form by the differential solution of dense limestone units, creating a honeycombed rock and by solution along joints and bedding surfaces between limestone and marl. Dissolution begins on the bedding surfaces and then dissolves the overlying limestone rather than the underlying marl. Water is commonly encountered beneath hard limestone beds. A drill bit will drop a few inches to a few feet after drilling through the limestone. The floor of the cavity is generally shale. This phenomenon is shown in figure 4, a measured section from the three-foot diameter drainage well 1001.

Groundwater Movement in Limestone Aquifers

In the Permian limestone aquifers groundwater storage and flow are predominantly in the solution cavities. The pore volume available for storage is small. Primary porosity is probably less than 5 percent. The storage coefficients, derived from two aquifer tests, were extremely small (6×10^{-5} and 4×10^{-4}). The storage coefficient indicates the amount of water in storage that is released from a unit volume of aquifer per unit decline of head. In these limestone aquifers there is little water available.

Groundwater flow is confined to the natural cavities and artificial cavities that are the results of unplugged seismic shot holes, abandoned oil wells and poorly-cased water wells. These numerous unplugged holes have interconnected the individual confined aquifers. The regional potentiometric surface (fig. 5) follows the topography of the land, whereas the local hydraulic gradient may be controlled by pumping wells in the area. Analysis of two aquifer tests yielded transmissivities (measurements of the rate of flow of water through a vertical section of an aquifer, whose height is the

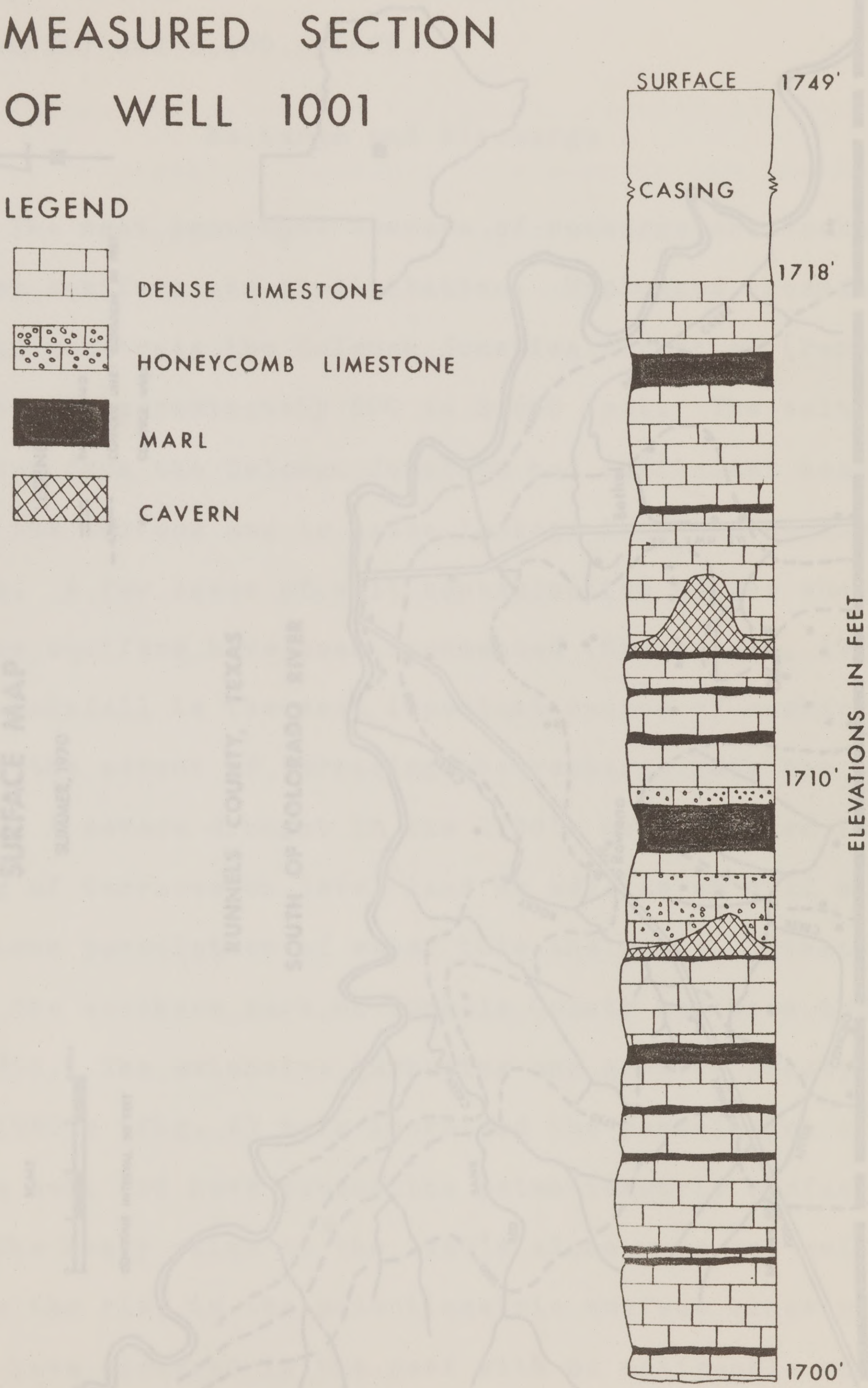

MEASURED SECTION
OF WELL 1001
LEGEND
DENSE LIMESTONE
HONEYCOMB LIMESTONE
MARL
CAVERN
SURFACE
1749'
CASING
1718'
1710'
1700'
ELEVATIONS IN FEET

Figure 4

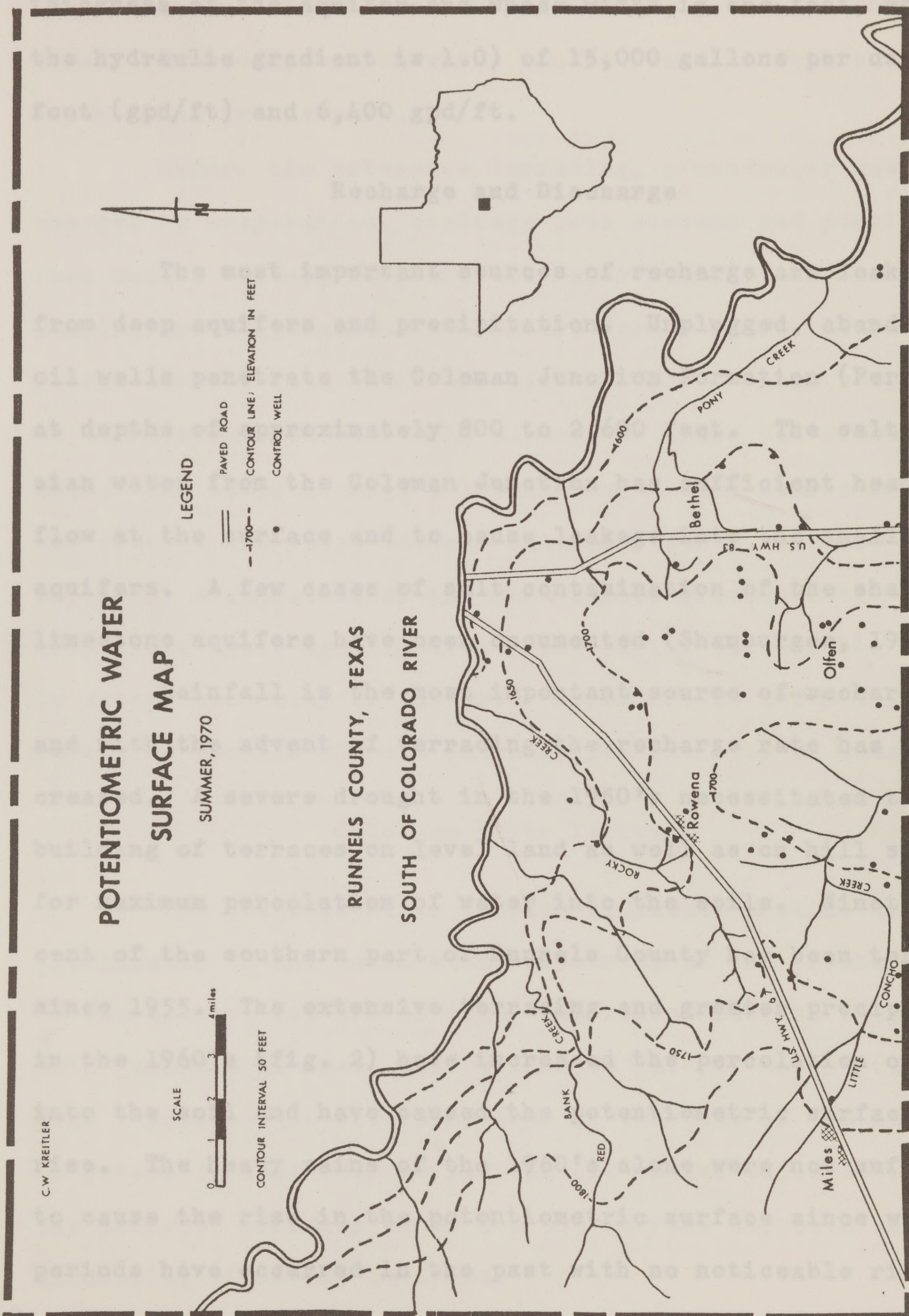

POTENTIOMETRIC WATER
SURFACE MAP
SUMMER, 1970
RUNNELS COUNTY, TEXAS
SOUTH OF COLORADO RIVER
C.W KREITLER
SCALE
0 1 2 3 4 miles
CONTOUR INTERVAL 50 FEET
LEGEND
PAVED ROAD
-1700- CONTOUR LINE; ELEVATION IN FEET
CONTROL WELL
N
PONY CREEK
ROCKY CREEK
RED BANK CREEK
LITTLE CONCHO CREEK
U.S. HWY. 83
U.S. HWY. 67
Bethel
Olfen
Rowena
Miles
1600
1650
1700
1750
1800
100°00'
31°45'
CONCHO COUNTY
TOM GREEN COUNTY
COKE COUNTY
TOM GREEN COUNTY

Figure 5

thickness of the aquifer and whose width is one foot, when the hydraulic gradient is 1.0) of 15,000 gallons per day per foot (gpd/ft) and 6,400 gpd/ft.

Recharge and Discharge

The most important sources of recharge are leakage from deep aquifers and precipitation. Unplugged, abandoned oil wells penetrate the Coleman Junction Formation (Permian) at depths of approximately 800 to 2,600 feet. The salty artesian water from the Coleman Junction has sufficient head to flow at the surface and to cause leakage into the shallow aquifers. A few cases of salt contamination of the shallow limestone aquifers have been documented (Shamburger, 1959).

Rainfall is the most important source of recharge, and with the advent of terracing the recharge rate has increased. A severe drought in the 1950's necessitated the building of terraces on level land as well as on hill sides for maximum percolation of water into the soils. Ninety percent of the southern part of Runnels County has been terraced since 1955. The extensive terracing and greater precipitation in the 1960's (fig. 2) have increased the percolation of water into the soil and have caused the potentiometric surface to rise. The heavy rains of the 1960's alone were not sufficient to cause the rise in the potentiometric surface since wetter periods have occurred in the past with no noticeable rise in the potentiometric surface (Werner Lange, personal communication). Currently, groundwater can be found at much shallower depths than in the past.

Before the extensive terracing, groundwater was discharged by evaporation, drainage into streams and pumping from wells. Today, however, the major means of discharge are pumping and evaporation. Seeps are formed where the potentiometric surface intersects the land surface. These seeps occur in depressions, on some hill slopes and along old stream channels. The seeps undergo a transition; a seep starts fresh, but after a few years becomes extremely salty, because of the continual evaporation of the mineralized groundwater. These areas lose their agricultural productivity because the soil is either too salty or too wet. Holes No. 26 and No. 30 (Appendix A) provide nitrate and chloride profiles of seep areas.

Colorado River Terraces

The Colorado River terrace sediments provide some groundwater to the total water resources of the southern part of the county, but are of minor importance because they are thin (maximum 40 feet) and of limited lateral extent (less than 1 mile). The saturated zone at the base of the terraces is generally less than 10 feet thick. Water wells located on the terraces commonly penetrate the terrace deposits and tap the underlying limestone aquifers.

QUALITY OF GROUNDWATER

Water samples were analyzed by the U. S. Public Health Service for silica, calcium, magnesium, sodium, bicarbonate, sulfate, chloride, fluoride, nitrate, total nitrogen, organic carbon, and total dissolved solids. These data are considered reliable, because samples prepared with known ionic concentrations closely agreed with the U.S.P.H.S. analyzed values. Water quality data are listed in Appendix C. Comparisons were made between the analyzed ionic species. Comparisons were also made between the distance from collection points to sources of contamination and the ionic species. No correlations were found.

Groundwater in the southern part of Runnels County generally is of very poor quality. The general water type shown on the Piper (1944) diagram (fig. 6) is calcium-magnesium-chloride water. There are also a few high sulfate waters.

Nitrate

Nitrate concentrations ranged from less than 0.4 mg/l to 3,584 mg/l. Only ten percent of 126 water samples analyzed were below the recommended limit of 45 mg/l nitrate for drinking water established by the U. S. Public Health Service (1962). The distribution of nitrate concentrations in the

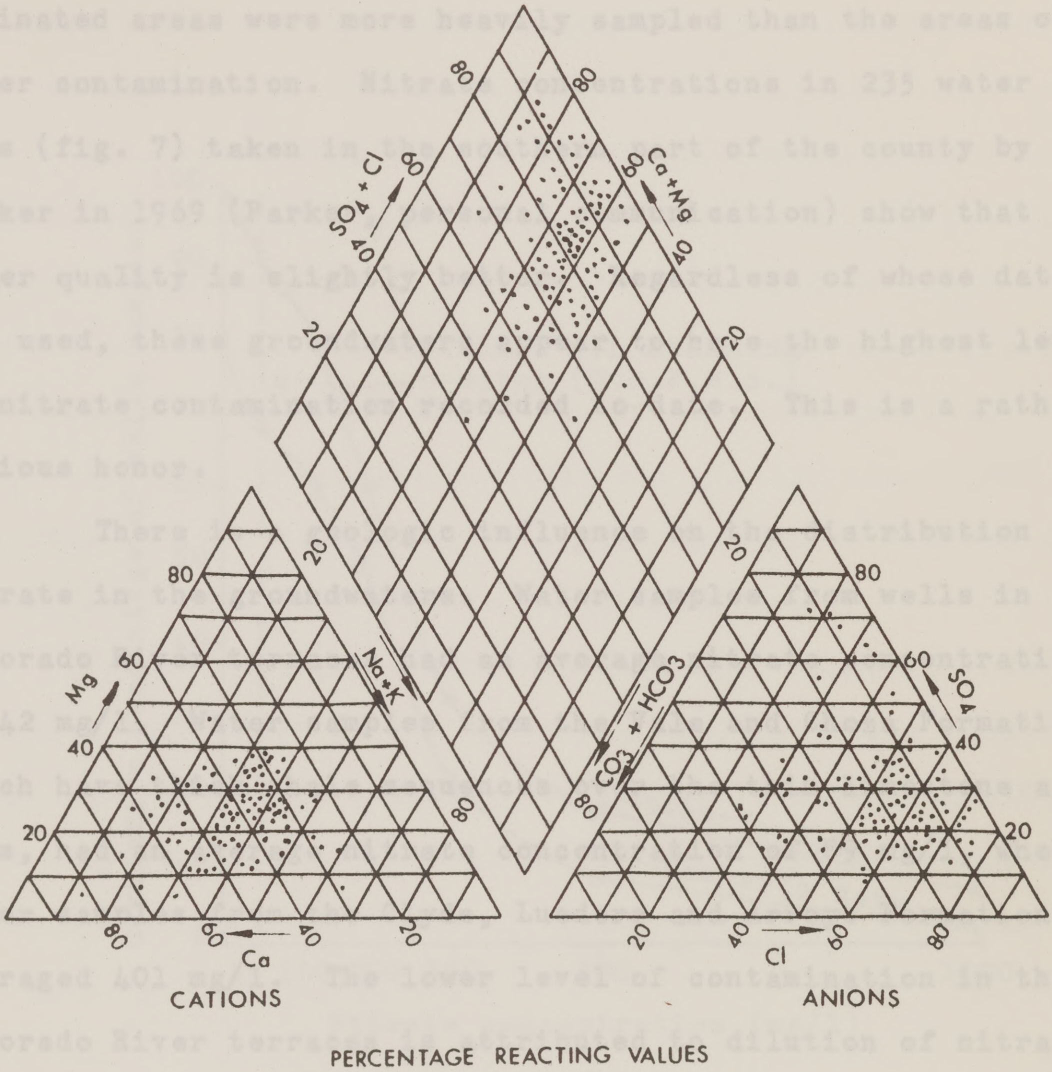


Figure 6. Trilinear diagram based on the percentage of milliequivalents per liter (128 samples).

water samples is given in figure 7. The nitrate distribution is biased toward higher concentrations because the badly contaminated areas were more heavily sampled than the areas of lower contamination. Nitrate concentrations in 235 water samples (fig. 7) taken in the southern part of the county by Parker in 1969 (Parker, personal communication) show that the water quality is slightly better. Regardless of whose data are used, these groundwaters appear to have the highest levels of nitrate contamination recorded to date. This is a rather dubious honor.

There is a geologic influence on the distribution of nitrate in the groundwaters. Water samples from wells in the Colorado River terraces had an average nitrate concentration of 42 mg/l. Water samples from the Vale and Choza Formations, which have thick shale sequences over the thin limestone aquifers, had an average nitrate concentration of 89 mg/l, whereas water samples from the Clyde, Lueders and Arroyo Formations averaged 401 mg/l. The lower level of contamination in the Colorado River terraces is attributed to dilution of nitrate in the alluvial deposits. Contamination levels in the limestone aquifers are higher because of the lack of dilution. An aquifer with a porosity of 25 percent (e.g., a gravel aquifer) will dilute a contaminant five times more than an aquifer with a porosity of 5 percent (e.g., a limestone aquifer). Limestone aquifers in the Vale and Choza Formations have lower

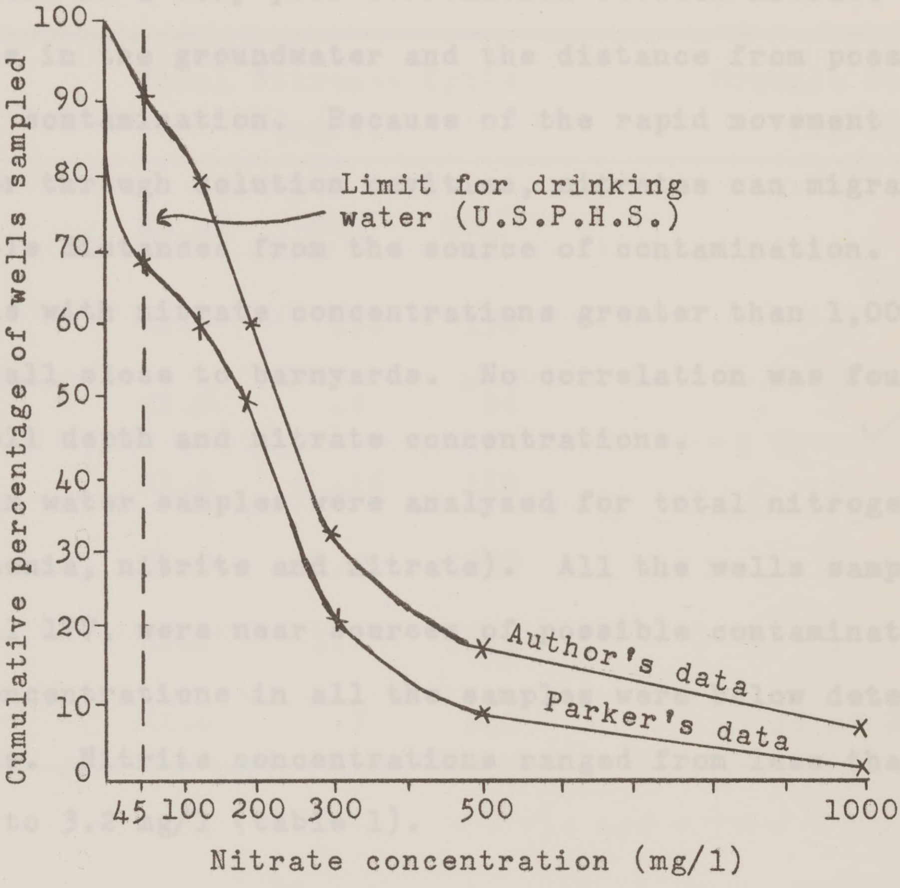


Figure 7. Distribution of nitrate in groundwater. Graph interpretation: 90 percent of the wells sampled by the author had nitrate concentrations greater or equal to 45 mg/l.

nitrate concentrations than the Clyde, Lueders and Arroyo Formations because of the thick blanket of clay overlying the aquifers, which reduces infiltration of contaminated water from the surface.

There is a very poor correlation between nitrate concentrations in the groundwater and the distance from possible sources of contamination. Because of the rapid movement of groundwater through solution cavities, nitrates can migrate considerable distances from the source of contamination. However, wells with nitrate concentrations greater than 1,000 mg/l were all close to barnyards. No correlation was found between well depth and nitrate concentrations.

Six water samples were analyzed for total nitrogen cycle (ammonia, nitrite and nitrate). All the wells sampled, except well 177, were near sources of possible contamination. Ammonia concentrations in all the samples were below detectable limits. Nitrite concentrations ranged from less than 0.16 mg/l to 3.2 mg/l (table 1).

Other Chemical Species

Other chemical species important to water quality are calcium, magnesium, sodium, bicarbonate, chloride, sulfate and organic carbon. Most of the water samples exceeded the concentration limits set by the U. S. Public Health Service (1962) or Davis and Dewiest (1967). Limits suggested by Davis

Table 1. Total nitrogen-organic carbon

Well No.	Total Nitrogen Cycle (mg/l)			Organic Carbon (mg/l)
	NH_3-N	NO_2^-	NO_3^-	
114	<1.0	.52	136	1
177	<1.0	.2	36	1
210	<1.0	< .16	110	5
727	<1.0	3.2	1302	2
865	<1.0	1.2	1245	1
1034	<1.0	.7	840	35 or 2

and Dewiest (p. 121, 1967) are used when there has been no suggested limit set by the U. S. Public Health Service. Only two percent of the samples analyzed were below the recommended limit of 500 mg/l for total dissolved solids in drinking water set by the U. S. Public Health Service (1962).

Calcium concentrations ranged from 60 mg/l to 1,400 mg/l with 55 percent of the water samples below the recommended limit of 250 mg/l set by Davis and Dewiest (1967). The source of the calcium is predominantly limestone and gypsum. Animal wastes are an additional source of calcium, although the magnitude of their contribution is not known. Each ton of cattle manure contains approximately three pounds of calcium (Loehr, 1969, p. 197). The fate of this calcium is not known.

Magnesium concentrations ranged from 15 mg/l to 332 mg/l, with 71 percent of the water samples below the recommended limit of 125 mg/l set by Davis and Dewiest (1967). The source of the magnesium is limestone and dolomite plus an unknown addition from animal wastes. Every ton of cattle manure contains approximately two pounds of magnesium (Loehr, 1969, p. 197).

Sodium concentrations ranged from 24 mg/l to 1,270 mg/l with only 38 percent of the water samples below the recommended limit of 200 mg/l set by Davis and Dewiest (1967). Leakage from the saline Coleman Junction aquifer and leakage from brine disposal pits probably contribute to the high sodium concentrations.

Bicarbonate analyses of the water samples are not accurate. The water samples were analyzed several days after collection, permitting the water to degas, changing the carbonate equilibrium.

Chloride concentrations ranged from 5 mg/l to 3,000 mg/l with only 19 percent of the water samples below the recommended limit of 250 mg/l for drinking water set by the U. S. Public Health Service (1962). Possible sources of the chloride are connate water, leakage from the Coleman Junction saline aquifer, and contamination from brine disposal pits and animal wastes. High chloride concentrations were found in the soils beneath barnyards.

Sulfate concentrations ranged from 13 mg/l to 3,100 mg/l, with 40 percent of the water samples below the recommended limit of 250 mg/l set by the U. S. Public Health Service (1962). Probable sources are gypsum evaporites from the Arroyo Formation, sulfides in shales and sulfur compounds in animal wastes. Animal wastes are considered because every ton of cattle manure contains approximately 1.5 pounds sulfur (Loehr, 1969, p. 197).

Six water samples were analyzed for organic carbon. The results were unreliable, because two duplicate samples from well 1034 did not agree (table 1).

NITRATE CONCENTRATIONS IN SOIL AND BEDROCK

Forty-six holes were drilled in different geologic and cultural settings to determine nitrate concentrations in the soil and bedrock (table 2). A hole-by-hole interpretation of the nitrate concentrations is given in Appendix A.

At each drilling site soil samples were collected every foot to a depth of twenty feet or until the water table was reached. Soil moisture was not determined. Samples were analyzed later for nitrate and chloride. One-quarter pound of sample was mixed with 500 ml of deionized water and allowed to sit for 15 minutes. The suspension was then analyzed for nitrate and chloride concentrations with an Orion, Inc., nitrate specific-ion electrode, model number 94-17A; a chloride specific-ion electrode, model number 92-07; and a single-junction reference electrode, model 90-01. Nitrate and chloride values, recorded in millivolts, were converted to milligrams per kilogram (mg/kg), by plotting millivolts on a calibration curve whose slope agreed with the Nernst equation (Manahan, 1969). The calibration curve was prepared by plotting millivolts against the log of concentration for three standards; one standard was used for each log cycle. Nitrate calibration curves were also derived for different chloride concentrations. The soil samples were analyzed in groups of twenty with standardization of the nitrate and

Table 2. Total nitrate in the soil

Hole No.	Total Pounds NO_3 15 Acre-ft.	Hole No.	Total Pounds NO_3 15 Acre-ft.
1	31,200	24	32,000
2	3,700	25	16,000
3	7,700	26	6,000
4	4,900	27	3,200
5	3,700	28	3,800
6	2,700	29	2,400
7	6,400	30	4,400
8	4,300	31	5,900/13 ft
9	2,500	32	23,100
10	2,600	33	20,100
11	1,700	34	5,300
12	14,200	35	5,800
13	20,700	36	3,900
14	3,600	37	3,700
15	11,400	38	8,200
16	11,000	39	6,700
17	5,400	40	40,000
18	16,400	41	59,500
19	3,700	42	19,900
20	3,600	43	79,000
21	26,100	44	4,700
22	30,000	45	14,300
23	16,000	46	17,300

chloride electrodes before and after each run with samples of known concentrations. Twenty random samples were checked by wet chemical analysis by Radian Corporation to determine the accuracy of the nitrate electrode (table 3). Analyses with concentrations of 10 mg/l or more were within ten percent of the wet chemical analyses. Analyses of concentrations with less than 10 mg/l were commonly more than 30 percent greater than the chemical analyses. Because of all the steps taken to determine the nitrate concentrations in the soils, a 20 percent error seems likely. Considering the number of samples analyzed and the difficulty of obtaining reproducable results in natural systems, plus the extremely high concentrations of nitrate, these experimental errors are acceptable.

Chloride measurements were made to determine the chloride interference with the nitrate determinations. At low nitrate concentrations (less than 50 mg/l) and high chloride concentrations (greater than 100 mg/l), nitrate concentrations determined with the electrode were higher than the wet chemical analyses. When necessary, nitrate values were corrected for chloride interference. Chloride concentrations are graphed with the nitrate concentrations in Appendix A.

Table 3. Nitrate concentrations from specific-ion electrode and wet chemical analyses

Sample Number	Nitrate Concentration by Specific-Ion Electrode (mg/l)	Nitrate Concentration by Wet Chemistry (mg/l)
3-3	70	58
10-12	5	1.9
12-3	103	100
16-8	46	50.4
17-9	13	2.8
18-4	54	41
19-14	7	1.2
20-14	10	5.3
21-1	55	58.7
22-3	6	2.0
23-8	13	8.7
25-0	20	19.2
25-7	6	2.9
26-3	23	5.4
27-5	37	31.4
27-1	130	120.4
28-1	170	165
29-20	8	1.3
30-5	67	57.5
31-9	6	0.7
32-12	7	0.3
33-1	21	8.1
34-6	27	14.4

POSSIBLE NITRATE SOURCES

Geologic Sources

Potential geologic sources of nitrate are organic-rich shales, limestones, and evaporite deposits. Trask and Patnode (1942) reported nitrogen concentrations up to 8,600 mg/l in organic-rich shales. Limestones with nitrate concentrations of 15 mg/l have been reported (Keeney and Gardner, 1970, p. 98). Nitrates were found in the shales and limestones sampled during drilling in Runnels County, but the age of the nitrates cannot be determined and may be Permian through Recent. Nitrate evaporites may occur in playa deposits, caliche deposits and cave deposits (Mansfield and Boardman, 1932), however, no nitrates were found in the gypsum lenses of the Arroyo Formation in Runnels County. It is unlikely that the nitrates have been removed by leaching because there are no solution cavities associated with the gypsum lenses, and the gypsum is always bone dry.

Leguminous Plants

Leguminous plants commonly fix 40 to 200 pounds of nitrogen per acre per year (Allison, 1955, p. 230). The mesquite tree is the only legume found in abundance in Runnels County, but soil samples taken from mesquite pastures did not have high nitrate concentrations.

Fertilizer

Commoner (1970), Kor and Schneider (1968), Stout and Burau (1967), Behnke and Haskell (1968), and Harmeson and Larson (1970) consider fertilizers as the major source of nitrates in their respective study areas. Fertilizer is not an important source in Runnels County, because it is rarely used. Because of the low rainfall and the lack of irrigation in the county, fertilizer burns the crops. Fertilizer is used only on small irrigated, bermuda grass pastures.

Industry

There is no industry in the southern part of Runnels County other than a few small oil concerns.

Precipitation

Junge (1958) reported high nitrate and ammonia concentrations in the rainfall of west Texas. The average nitrate and ammonia concentrations for a period of a year were approximately 1 mg/l nitrate and 0.1 mg/l ammonia. Using these concentrations for Runnels County, about 1 pound of nitrate per acre was added annually to the soil by 12 inches of rain. This estimate assumes complete conversion of ammonia to nitrate.

Suggested sources for this atmospheric ammonia and nitrate are photochemical reactions in the air (Feth, 1966, p. 45), wind-blown soil (Junge and Manson, 1961, p. 2177) and industrial activity. Gambell and Fisher (1964, p. 4208), Junge (1958, p. 245), Hoering (1957, p. 97) and Commoner (1970, p. 89) consider lightning of minor importance in the formation of atmospheric nitrate.

Animal Wastes

Livestock and humans produce prodigious quantities of organic wastes. Loehr (1969), Gillham and Webber (1969), Smith (1969), and Stewart _et al_. (1967) consider animal wastes as the major nitrate source in their study areas.

Nitrates in animal wastes originate as protein and urea. Under aerobic conditions the protein and urea are biologically oxidized to nitrate. The process is known as nitrification. The reactions are:

$$\text{Amino acids} \longrightarrow \text{Urea} \longrightarrow NH_3 \longrightarrow NO_2 \longrightarrow NO_3.$$

Urea is hydrolized to ammonia. The bacteria _Nitrosamanus_ oxidizes ammonia to nitrite and the bacteria _Nitrobacter_ oxidizes nitrite to nitrate. If conditions are dry most of the ammonia will be converted to nitrogen gas; if conditions are relatively wet most of the ammonia will be converted to nitrate.

A cow excretes approximately 0.4 pounds nitrogen every day (Loehr, 1969, p. 199). If 50 percent of this nitrogen is converted to nitrate .9 pound of nitrate will be created per cow per day or 330 pounds nitrate per cow per year; thus one cow per acre would add 330 times more nitrate to the soil than rainfall. Large quantities of nitrate are also being created by humans, hogs, sheep, goats and chickens (table 4).

Table 4. Nitrates produced from animal wastes (Loehr, 1969)

Animal	Total Nitrogen lb/day	Estimated Nitrate (50% conversion) lb/day
Chickens	0.003	0.007
Hogs	0.05	0.1
Cattle	0.4	0.9
Humans	0.033	0.07

DISCUSSION AND CONCLUSIONS

Discussion

Only 10 percent of the water samples analyzed were below the U. S. Public Health Service recommended limit for nitrate in drinking water. Most groundwater in Runnels County is not fit for human consumption.

To determine the sources of this contamination, soil samples from barnyards, septic tank fields, cultivated crop land, pasture land, mesquite thickets, and seep areas were analyzed. Comparisons of the nitrate profiles and the total nitrate for each of the profiles (Appendix A) show that the nitrate-rich soils are near septic tanks and areas of livestock confinement. Average total nitrate content was 26,700 pounds per 15 acre-feet; in other words, the upper 15 feet of soil and rock contains 26,700 pounds of NO_3 per acre. The cultivated fields had an average of 4,100 pounds of nitrate per 15 acre-feet and the pastures had an average of 3,900 pounds of nitrate per 15 acre-feet. The cultivated fields had slightly higher values than the pastures, probably because of greater soil aeration, which permits more organic nitrogen to be converted to nitrate. Total nitrates in mesquite thickets were about the same as in pastures. Seep areas have high nitrate concentrations at shallow depths, caused by the evaporation of nitrate-enriched groundwaters.

The seep areas are thus accumulation areas rather than source areas.

The total nitrate values in barnyards are higher than reported in other studies. The maximum nitrate per 15 acre-feet under corrals in Colorado was 26,000 pounds (Stewart *et al*., 1967) whereas the maximum amount of nitrate determined in this study area was over 70,000 pounds of nitrate per 15 acre-feet. A possible explanation for this large difference may be the difference in soil and rainfall and hence of leaching between the two areas. The nitrate values found in fields and pastures are also slightly higher than fields in Colorado (Stewart *et al*., 1967) and fields in Illinois (Harmeson and Larson, 1970). The nitrate profiles in Appendix A have not been changed to the wet chemical analysis values. All the low nitrate values shown are about 30 percent greater than their wet chemical analysis value. This analytical variance may be the small differences among the Colorado data, the Illinois data, and the Runnels County data, but the magnitude of the differences is not considered significant.

Extensive drilling on two farms confirmed the idea that the high nitrates occur in the soils near or under the barnyards and septic tanks. Samples from holes 20, 21, 22, 23, 24, 25 and 26 drilled on the O. Halfman farm showed that nitrate concentrations are much higher in the barnyard and septic tank areas. Samples from holes 38, 39, 40, 41, 42, 43 and 44 drilled on the P. Peiper farm also had much higher nitrate concentrations in the barnyard soils than in the field soils. This correlation is also seen in the comparison of nitrate profiles for holes 1 and 2; 13, 14, 15, and 16; 18 and 19; 31 and 32. More complete discussions of these data are given in Appendix A.

There is a strong correlation between nitrate and chloride concentrations in the soils. In profiles of contaminated soils the chloride peaks coincide with the nitrate peaks, whereas in the pastures and cultivated fields there are low or undetectable chloride concentrations. The high chloride concentrations in the barnyard soils should be expected, because of the high chloride content in cattle manure. Unfortunately, there is no definite correlation between chloride and nitrate in the groundwater.

Beneath barnyards nitrates migrate down to the water table by an increased percolation of nitrate-rich surface waters. A cow excretes a minimum of four gallons of water per day (Loehr, 1969, p. 195). In a pasture this water is evaporated or absorbed by the soil and the vegetation and much of the nitrate is used for plant growth. In the barnyard, where cattle are much more concentrated, the water from the excrement saturates the soil and either percolates down below the root zone to the potentiometric surface or evaporates, leaving a nitrate-rich zone. Because of the recent rise of the potentiometric surface, caused by the extensive terracing, groundwater has saturated these nitrate caliches and appears to have dissolved the accumulated nitrates.

The natural vertical permeability is low, because of the high clay and silt content, but it is greatly increased locally by outdated water well construction. Most of the farm wells are in barnyards and constructed of easily corrodable stove pipe. Surface water and perched groundwater can easily drain into the producing limestone aquifer (fig. 8). Water well No. 365 is an example of this high artificial vertical permeability. Water from the well had a nitrate concentration of 250 mg/l. At a depth of 19 feet, perched groundwater with a nitrate concentration of 1,000 mg/l was draining into the producing limestone aquifer.

The nitrate concentrations in the groundwater within the limestones are much higher than in groundwater in other aquifer types (i.e., gravels, sandstones), because of the lack of dilution in the limestones. For example, in a limestone aquifer, with a net thickness of five feet and 5 percent porosity, the maximum amount of water stored is .25 acre-feet, whereas in a sand and gravel aquifer, with a saturated thickness of five feet and 30 percent porosity, there would be 1.5 acre-feet of water in storage. If equal amounts

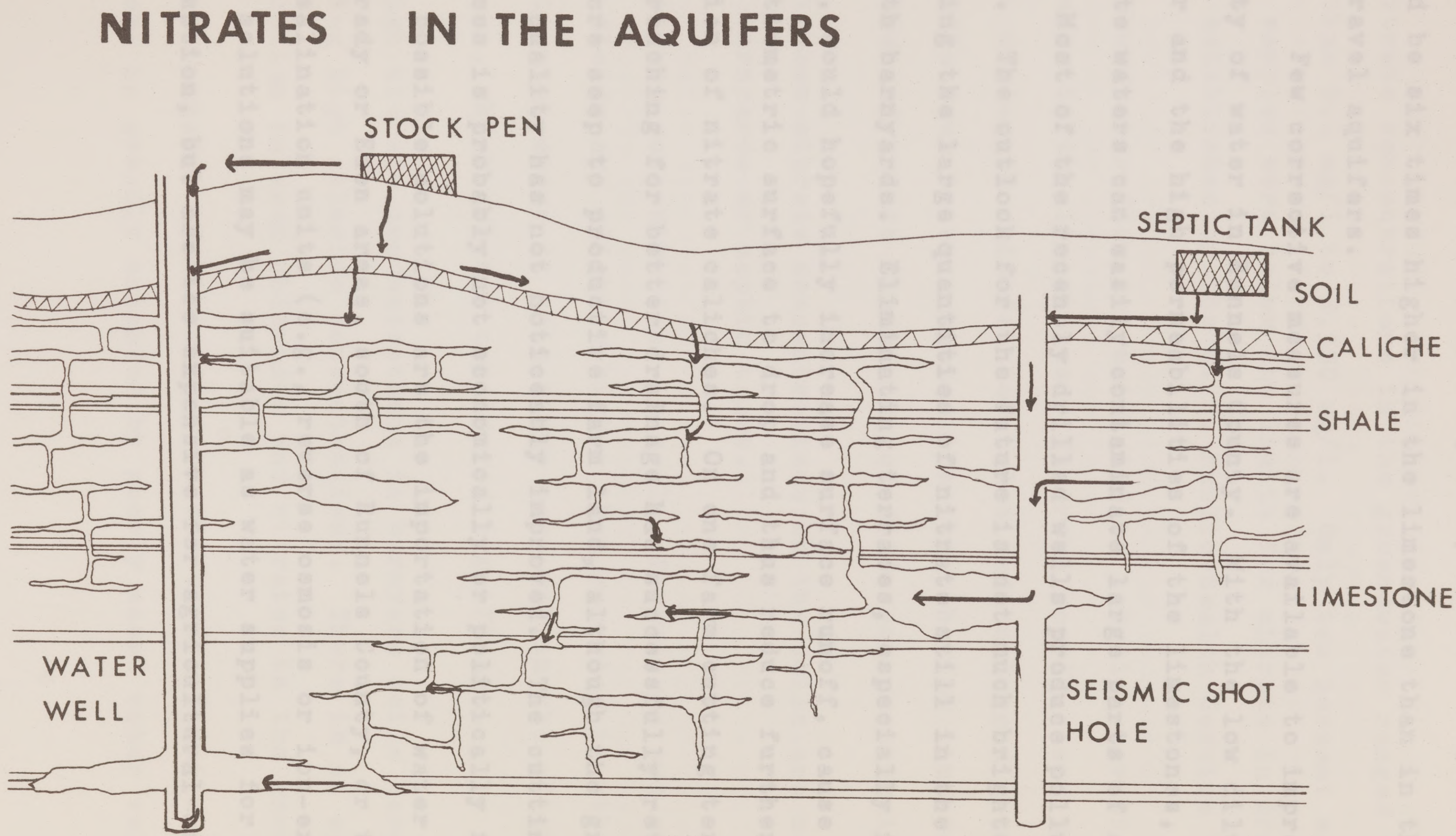

NITRATES IN THE AQUIFERS
STOCK PEN
SEPTIC TANK
SOIL
CALICHE
SHALE
LIMESTONE
WATER WELL
SEISMIC SHOT HOLE

Figure 8

of nitrate are added to each aquifer, nitrate concentrations should be six times higher in the limestone than in the sand and gravel aquifers.

Few corrective measures are available to improve the quality of water in Runnels County. With the low dilution factor and the high permeabilities of the limestones, high nitrate waters can easily contaminate large parts of an aquifer. Most of the recently drilled wells produce polluted water. The outlook for the future is not much brighter, considering the large quantities of nitrate still in the soils beneath barnyards. Eliminating terraces, especially in seep areas, would hopefully increase surface runoff, cause the potentiometric surface to drop and thus reduce further dissolution of nitrate caliches. On one farm cutting terraces and trenching for better drainage has successfully returned a 5 acre seep to productive farm land, although the groundwater quality has not noticeably improved. The cutting of terraces is probably not economically or politically feasible. Other possible solutions are the importation of water from the Brady or Eden areas, south of Runnels County, or the use of desalination units (e.g., reverse osmosis or ion-exchange). These solutions may be suitable as water supplies for human consumption, but are too expensive for agricultural use.

Conclusions

1. Nitrate concentrations in the groundwater ranged from less than 0.4 mg/l to 3,580 mg/l. Only ten percent of the water samples were below the limits for nitrate in drinking water established by the U. S. Public Health Service (1962).

2. Groundwater flow is restricted to solution cavities and fractures in the limestones. Numerous poorly cased water wells, unplugged seismic shot holes and unplugged abandoned oil wells have interconnected the thin shallow limestone aquifers and permit the mixing of different groundwaters.

3. Highest nitrate concentrations in the soils are near or under barnyards or septic tanks.

4. Nitrate concentrations in soils of pastures and cultivated fields are slightly higher than reported in other areas. Experimental error in this study may explain the slight differences, which are not considered significant.

5. High nitrate concentrations in barnyard soils have corresponding high chloride concentrations. There is no apparent correlation between chlorides and nitrates in the groundwater.

6. The transfer of nitrates from the barnyard soils to the aquifers is greatly enhanced by poorly cased water wells.

7. Extensive terracing has caused an appreciable rise in the potentiometric surface with subsequent dissolution of nitrate caliches by groundwater. Where the potentiometric surface has intersected the land surface, seepage areas have formed.

8. Nitrate concentrations in the groundwater within limestone aquifers are extremely high partly because of the low dilution in the limestone aquifers.

9. High nitrate concentrations are found in waters from wells far from contamination sources, because of the high permeability of the limestone aquifers.

10. Improvement of future groundwater quality cannot be expected because of the vast quantities of nitrate still in the soils. Water importation or desalination may prove economically feasible for human consumption, but not for agricultural needs.

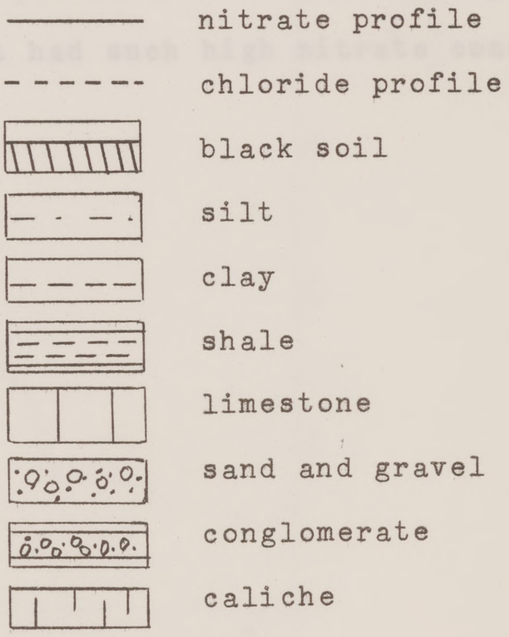
APPENDIX A

NITRATE AND CHLORIDE PROFILES

Nitrate and Chloride Profiles with Location Maps

This appendix includes the nitrate and chloride profiles, lithology, and discussion of probable nitrate sources at each borehole. Nitrate and chloride concentrations are shown numerically when values are greater than 900 mg/kg. Where chloride concentration is not shown, its value was less than 18 mg/kg. A location map follows each profile or set of profiles.

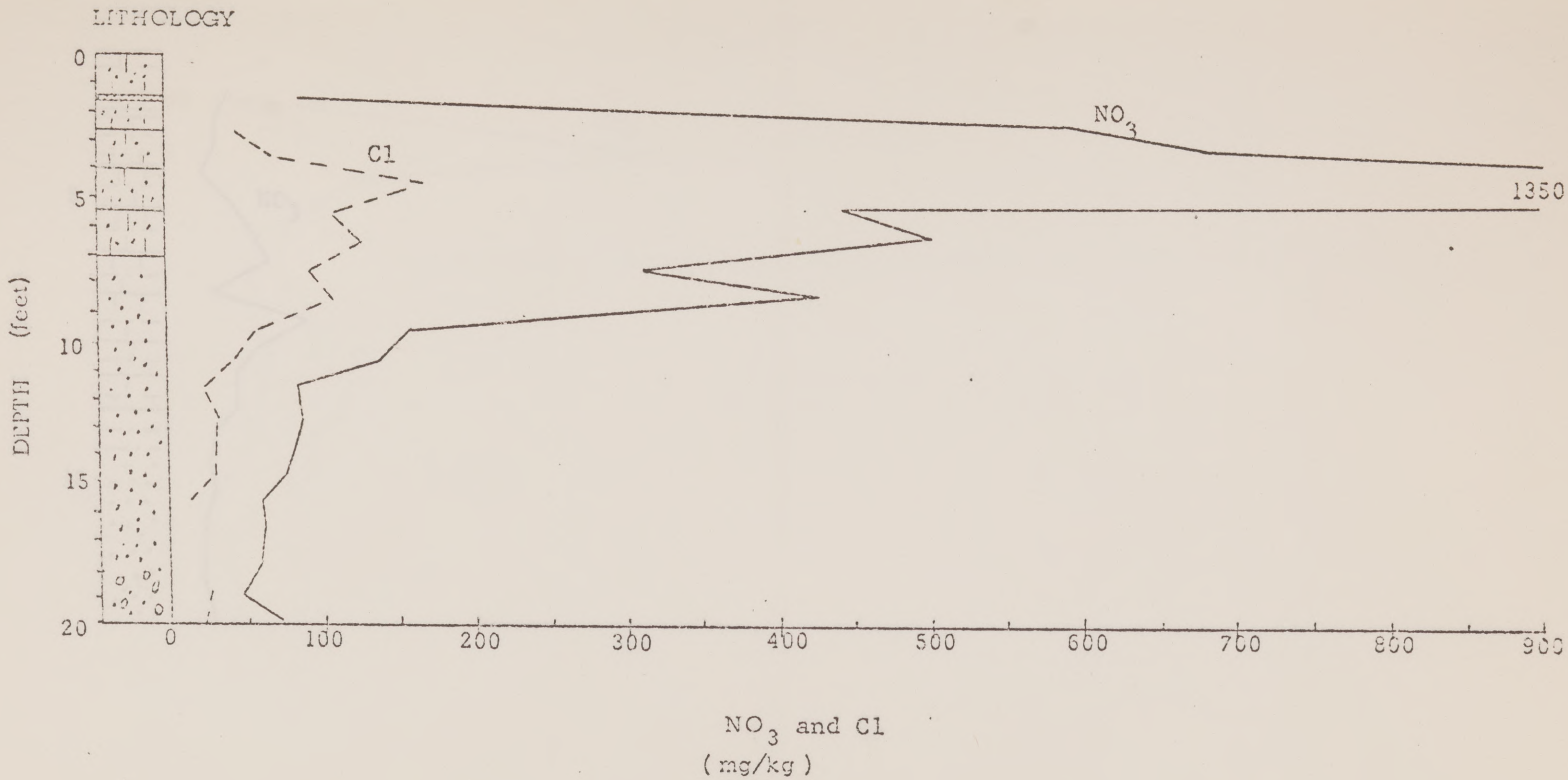
Explanation of Symbols



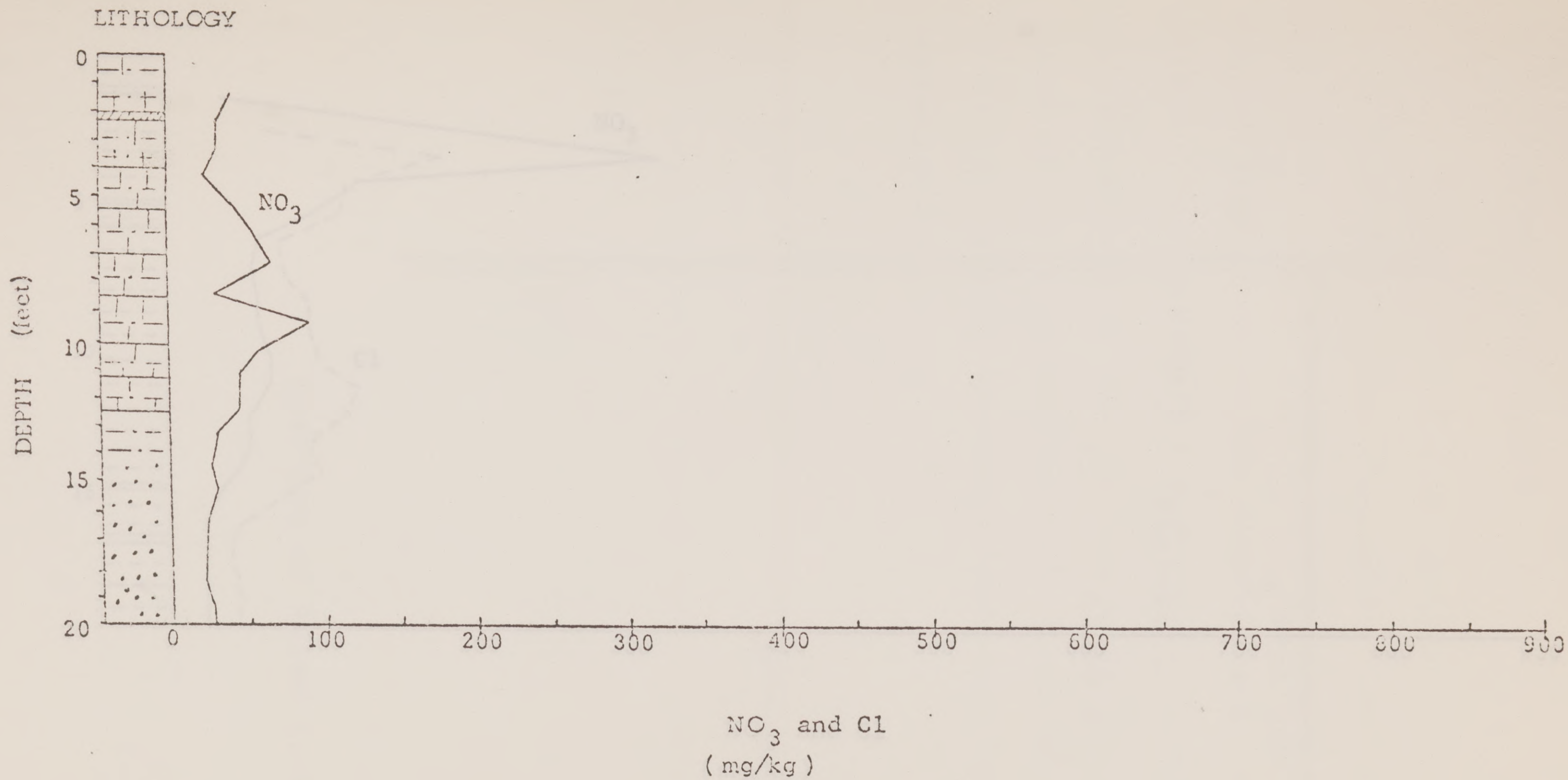
Hole 1, Hole 2, and Hole 3

Hole 1 was drilled ten feet south of water well 369. The high nitrates in the soil are probably due to the fact that well 369 was a watering hole for cattle and sheep for approximately fifty years. Hole 2 was drilled approximately 100 yards south of water well 369. Cattle had grazed this land, but had never been concentrated near Hole 2. A comparison of Hole 1 and Hole 2 shows the major source of contamination comes from the area where cattle had been watered.

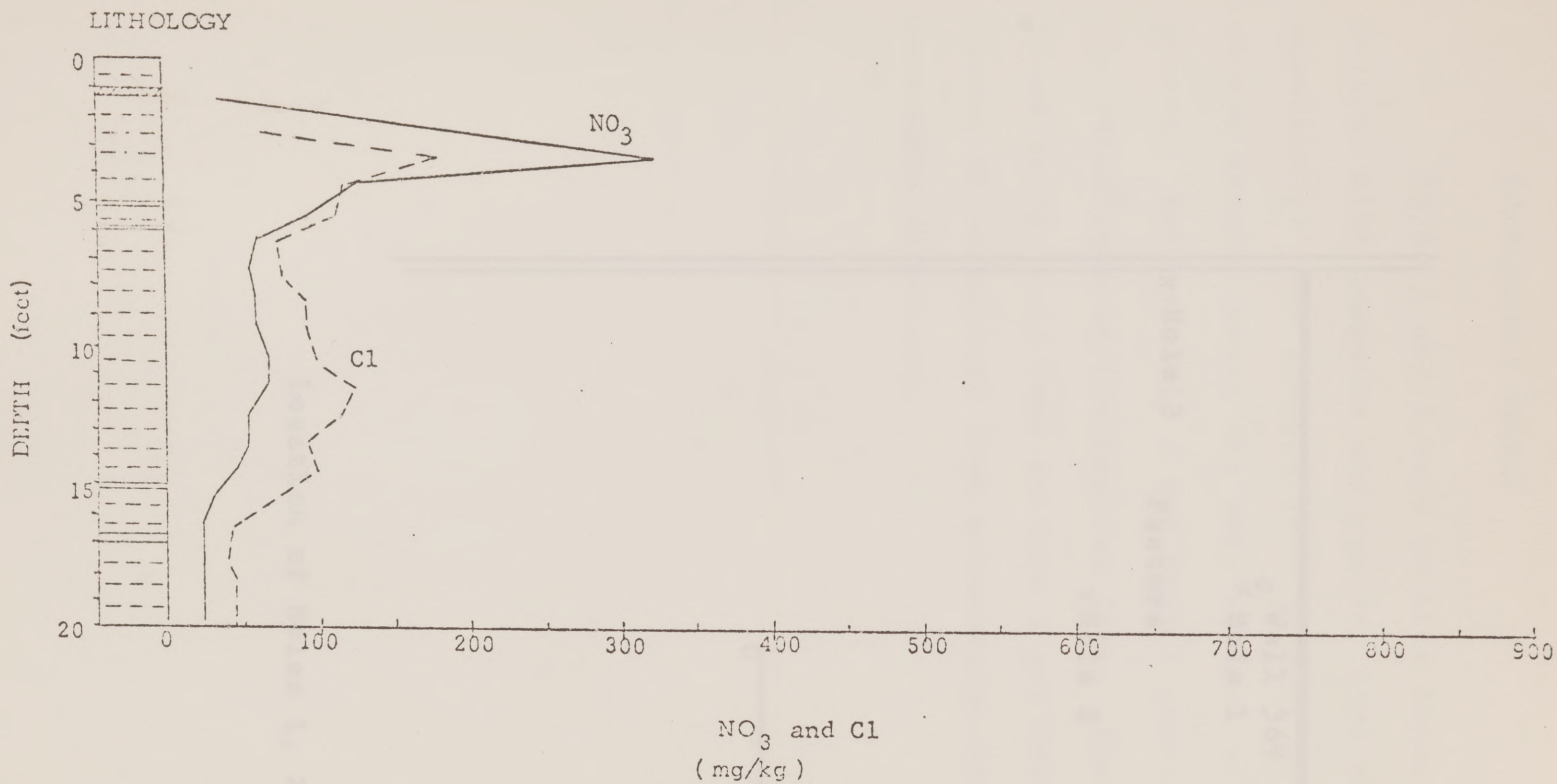
There is no adequate explanation for the high nitrate concentrations found at Hole 3, which is 250 yards west of well 369. The hole was drilled next to a pasture, but other pastures have not had such high nitrate concentrations.



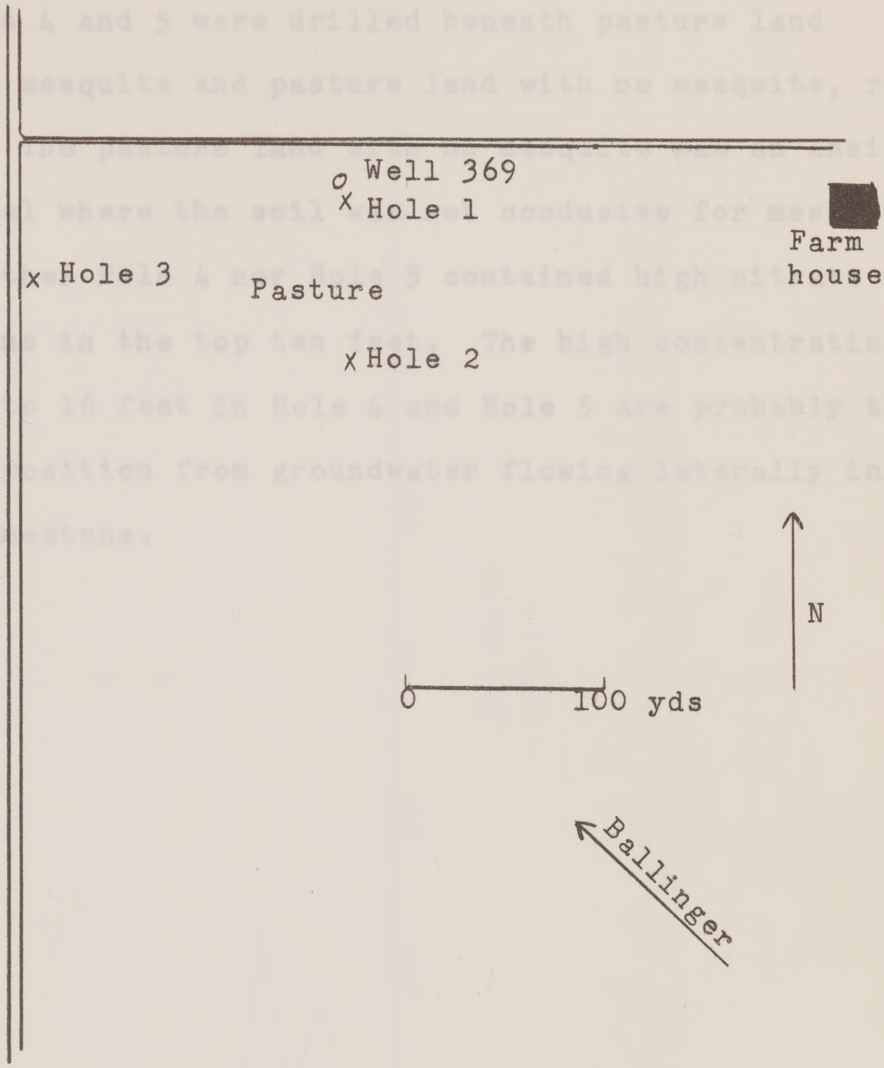
Hole 1. Located 10 feet south of water well 369. Sheep seen near the well several times.



Hole 2. Located in a cotton field, 100 yards south of water well 369. Cattle have grazed this area.



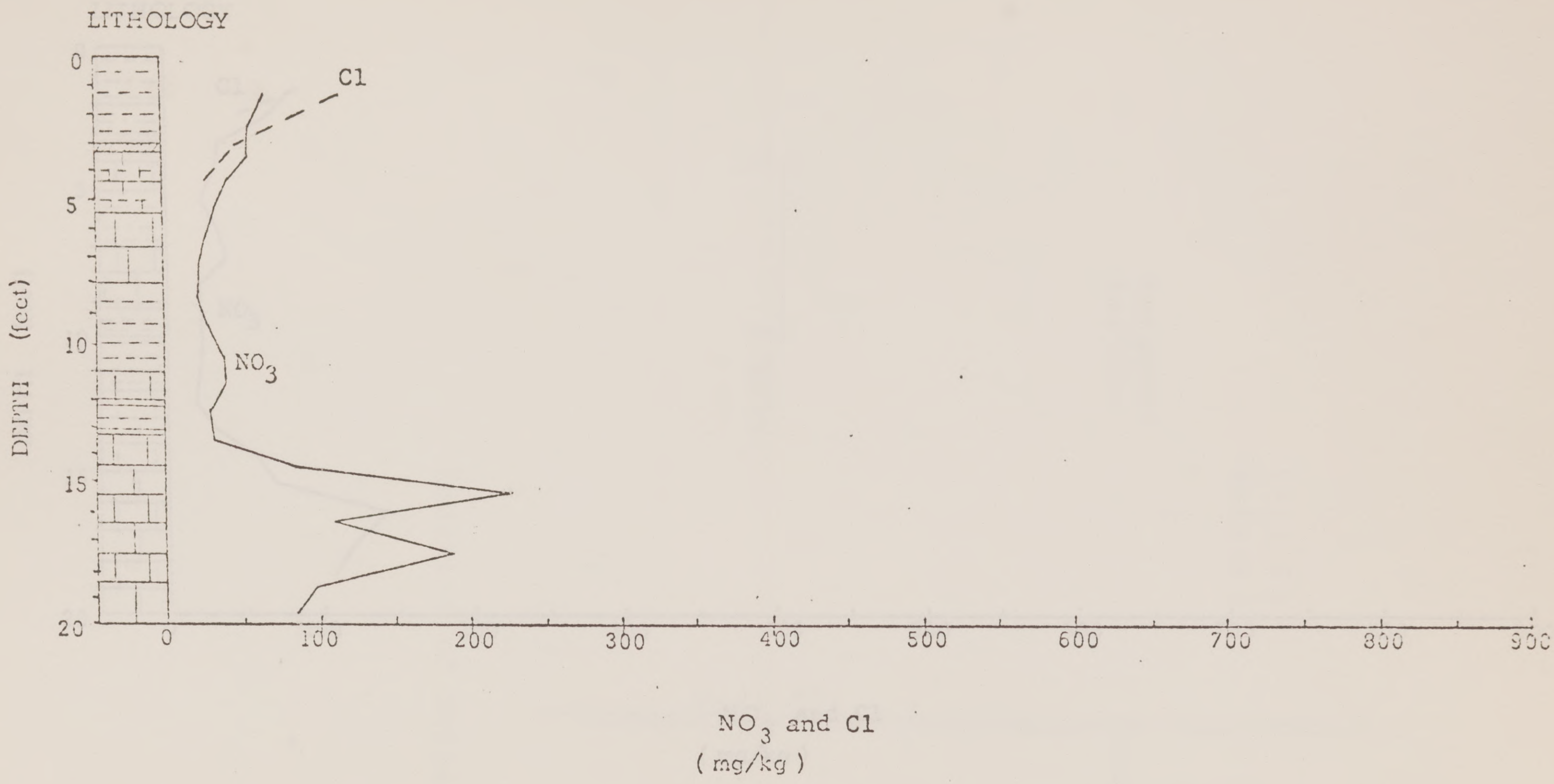
Hole 3. Located along a caliche road, 250 yards west of water well 369. Cattle had been grazing on both sides of the road.



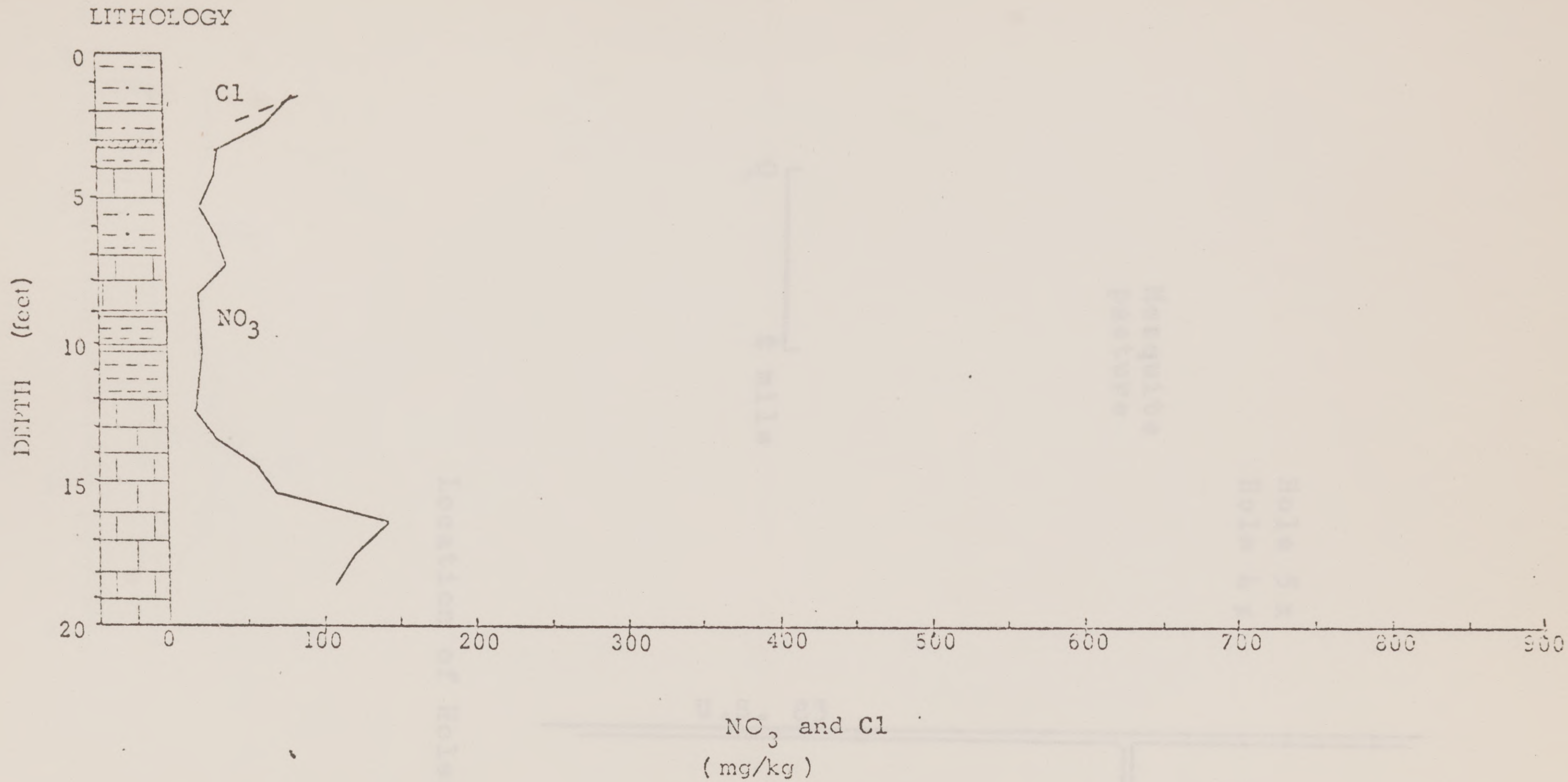
Location of Holes 1, 2, and 3

Hole 4 and Hole 5

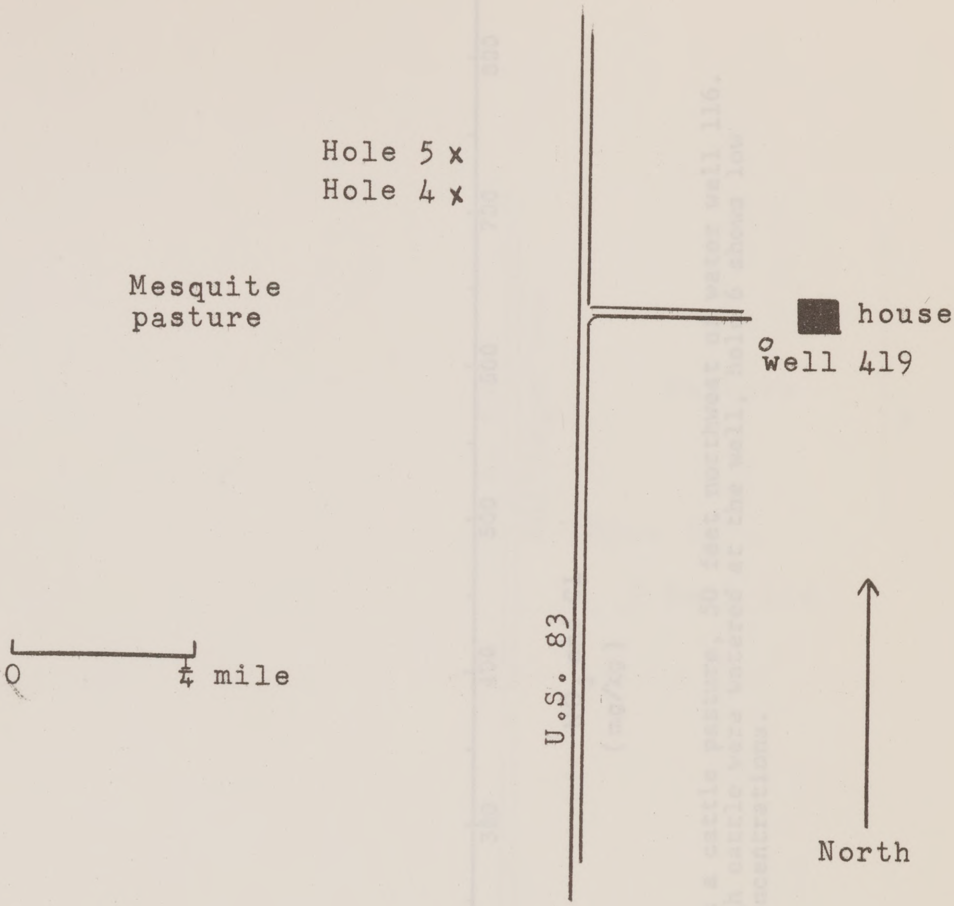
Holes 4 and 5 were drilled beneath pasture land covered with mesquite and pasture land with no mesquite, respectively. The pasture land with no mesquite was an ancient stream channel where the soil was not conducive for mesquite growth. Neither Hole 4 nor Hole 5 contained high nitrate concentrations in the top ten feet. The high concentrations found at 15 to 16 feet in Hole 4 and Hole 5 are probably the result of deposition from groundwater flowing laterally in a permeable limestone.



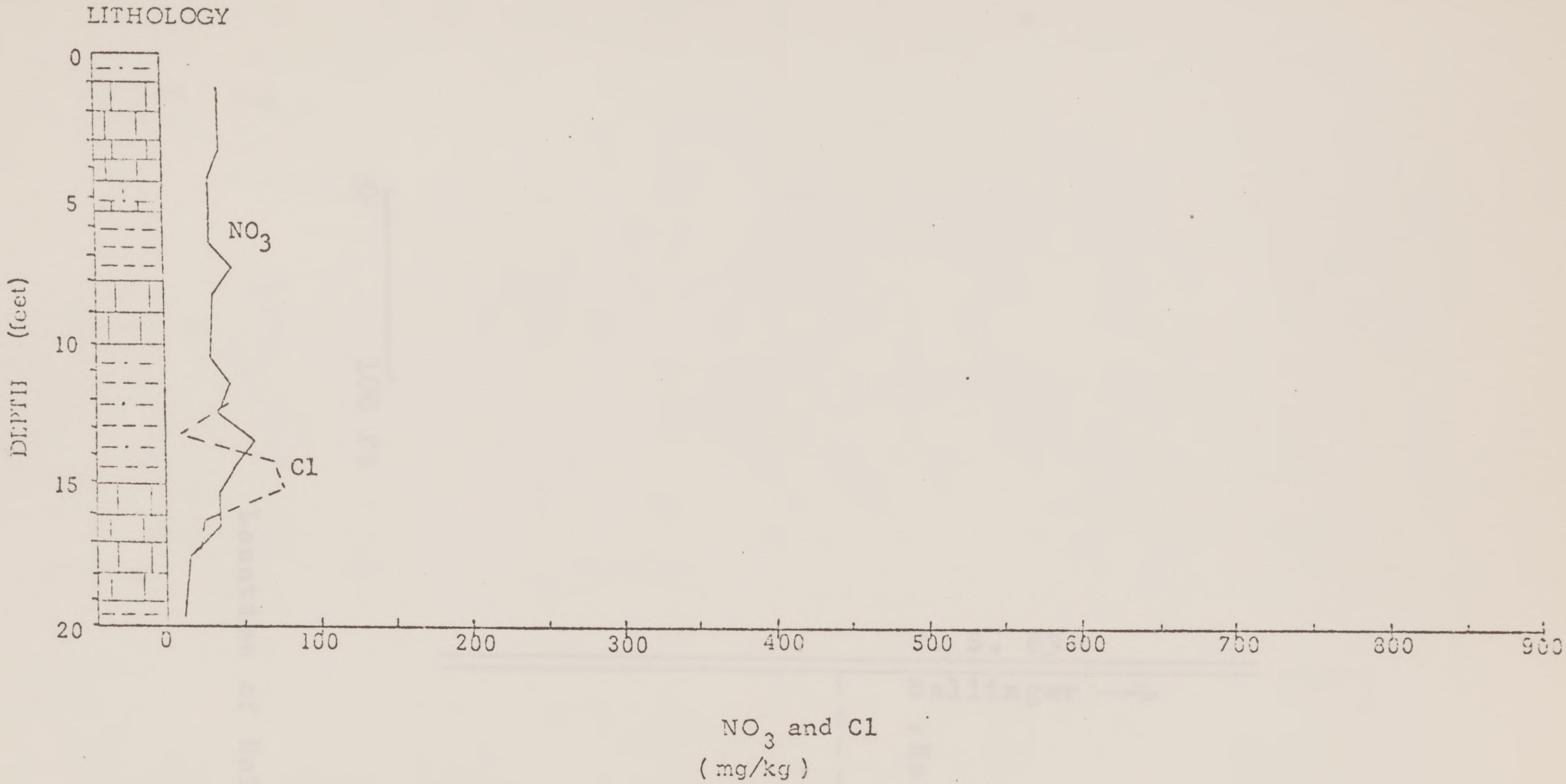
Hole 4. Located in a mesquite pasture, 100 feet south of Hole 5 and ¼ mile west of water well 419. Manure evident.



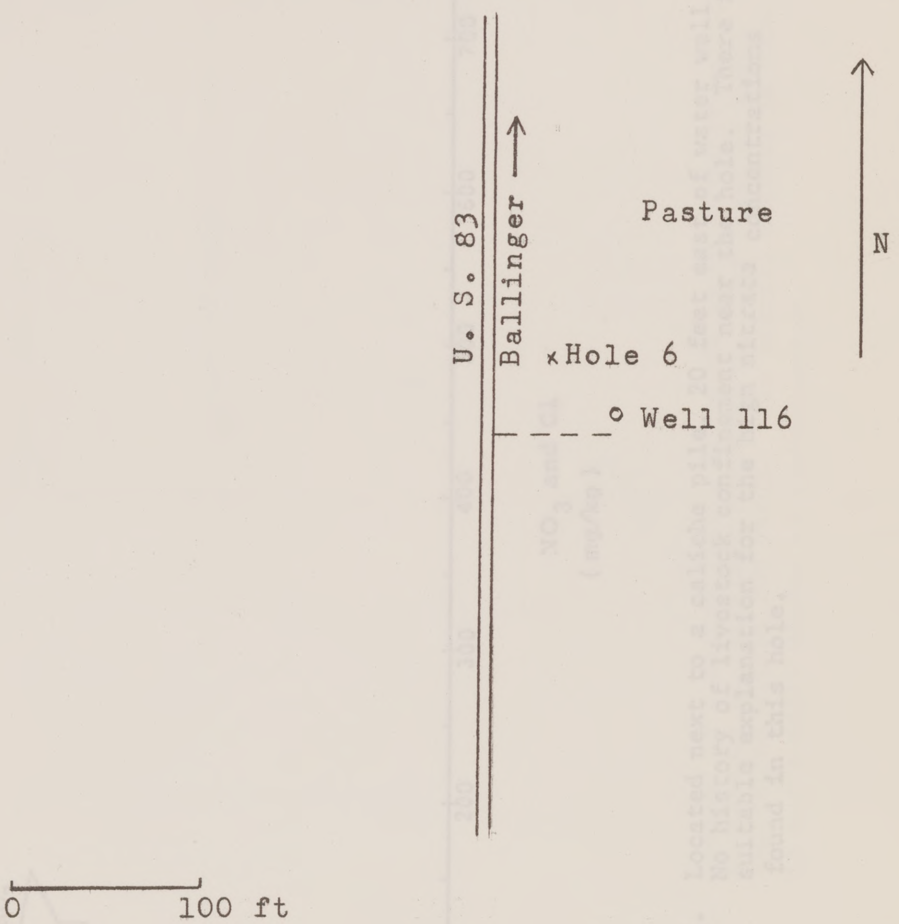
Hole 5. Located in an old stream bed that cuts through a mesquite pasture, 100 feet north of Hole 4 and ¼ mile west of water well 419. Manure evident. No mesquite.



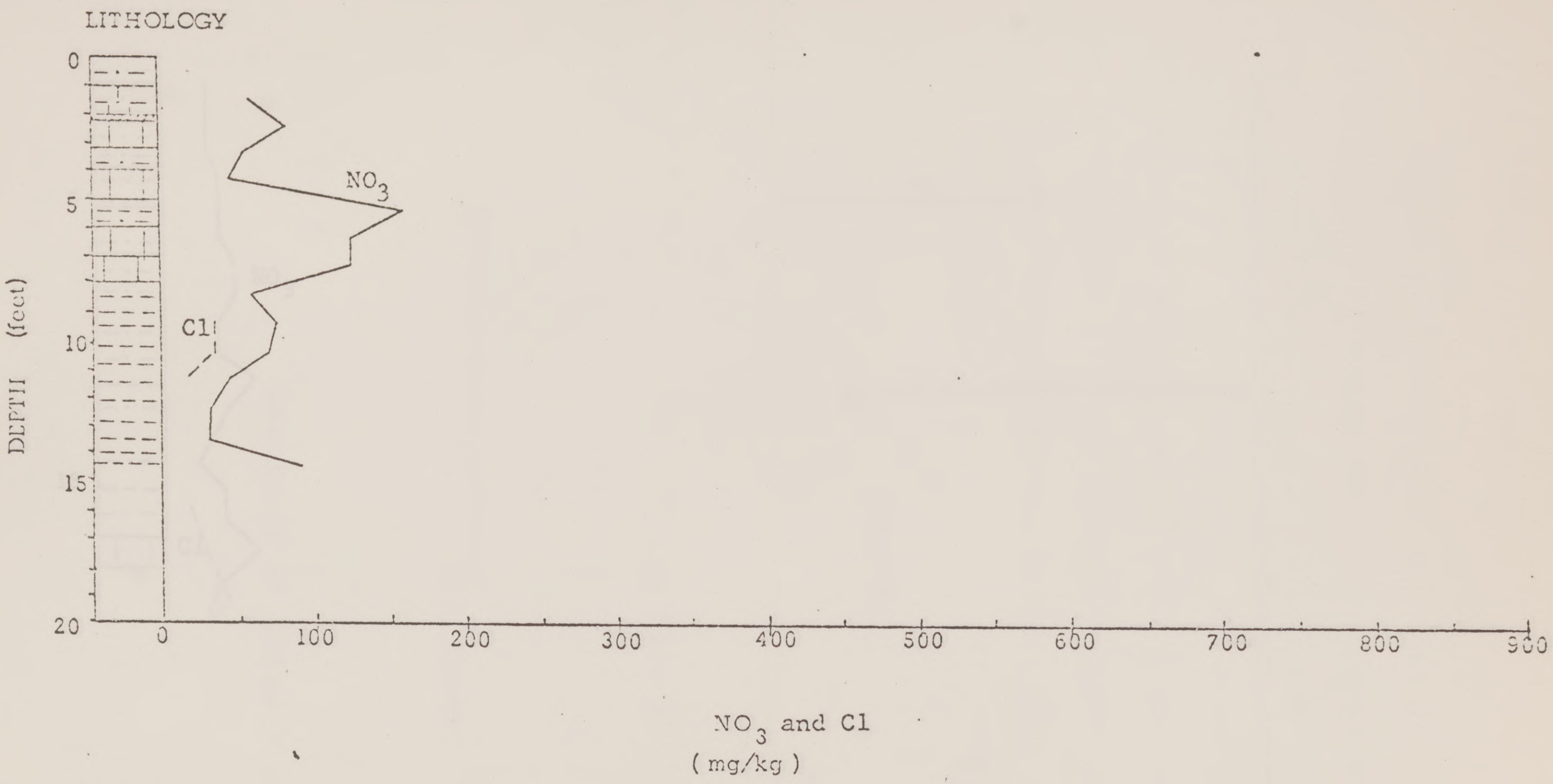
Location of Holes 4 and 5



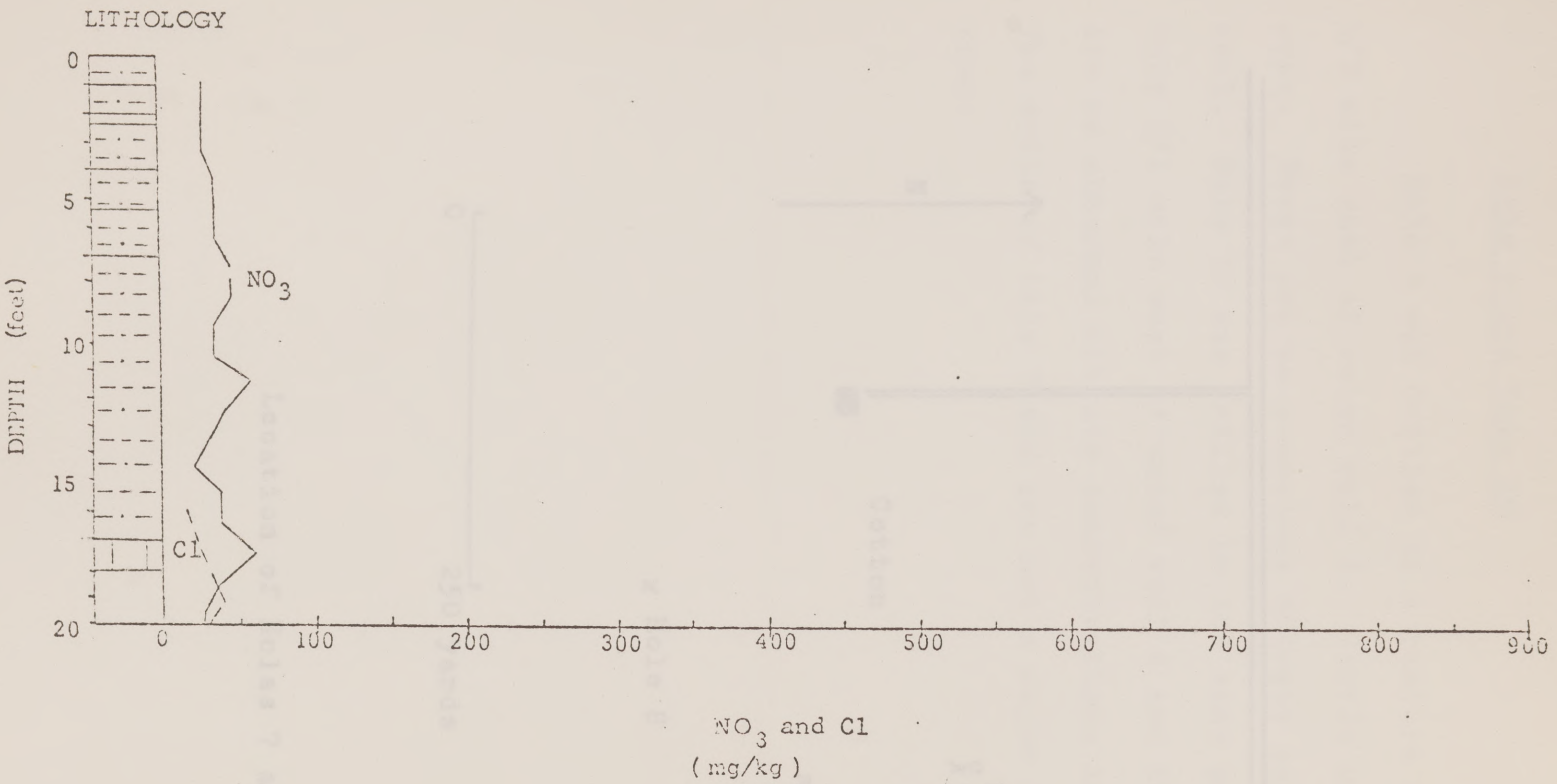
Hole 6. Located in a cattle pasture, 50 feet northwest of water well 116. Even though cattle were watered at the well, hole 6 shows low nitrate concentrations.



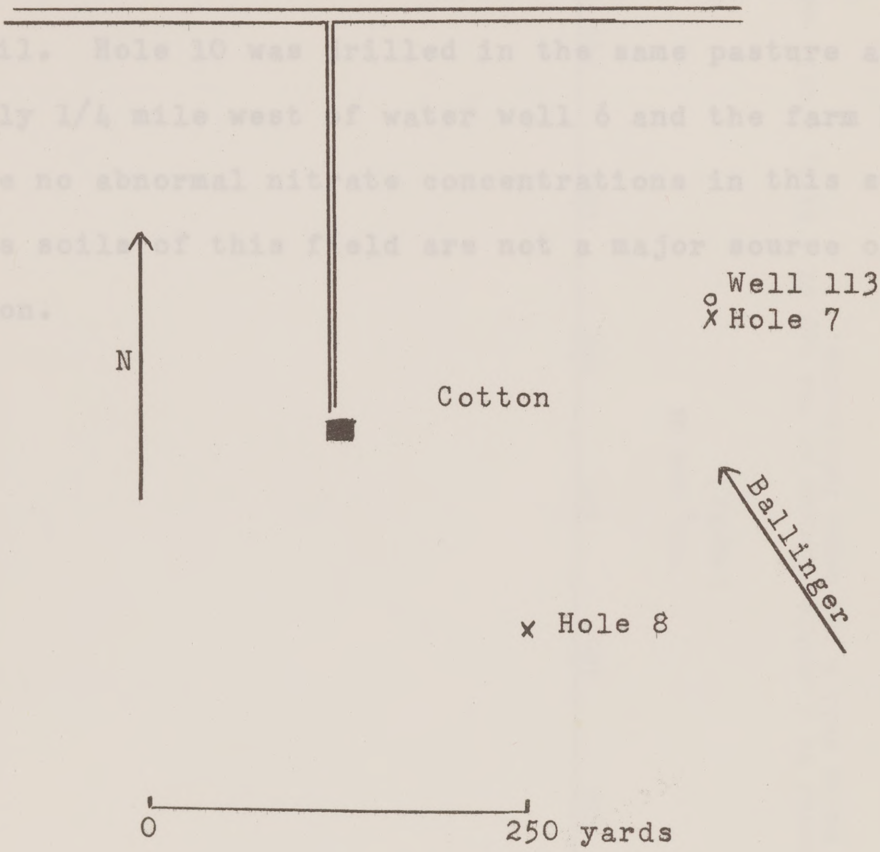
Location of Hole 6



Hole 7. Located next to a caliche pile, 20 feet east of water well 113. No history of livestock confinement near the hole. There is no suitable explanation for the high nitrate concentrations found in this hole.



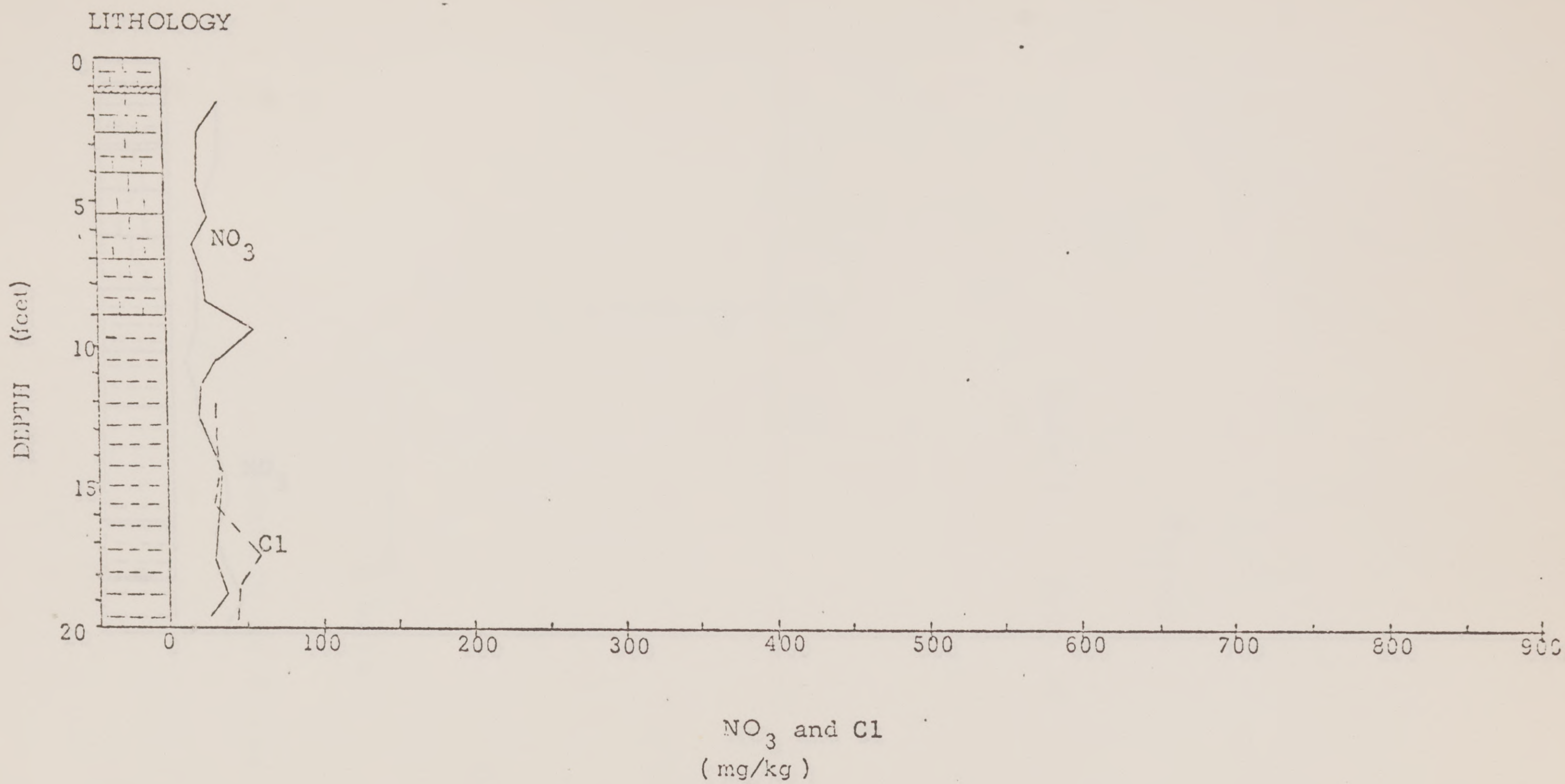
Hole 8. Located in a cotton field, 250 yards south of water well 113. No history of levestock confinement, fertilizer or human habitation within 200 yards. The natural nitrate in this is not a major source of contamination.



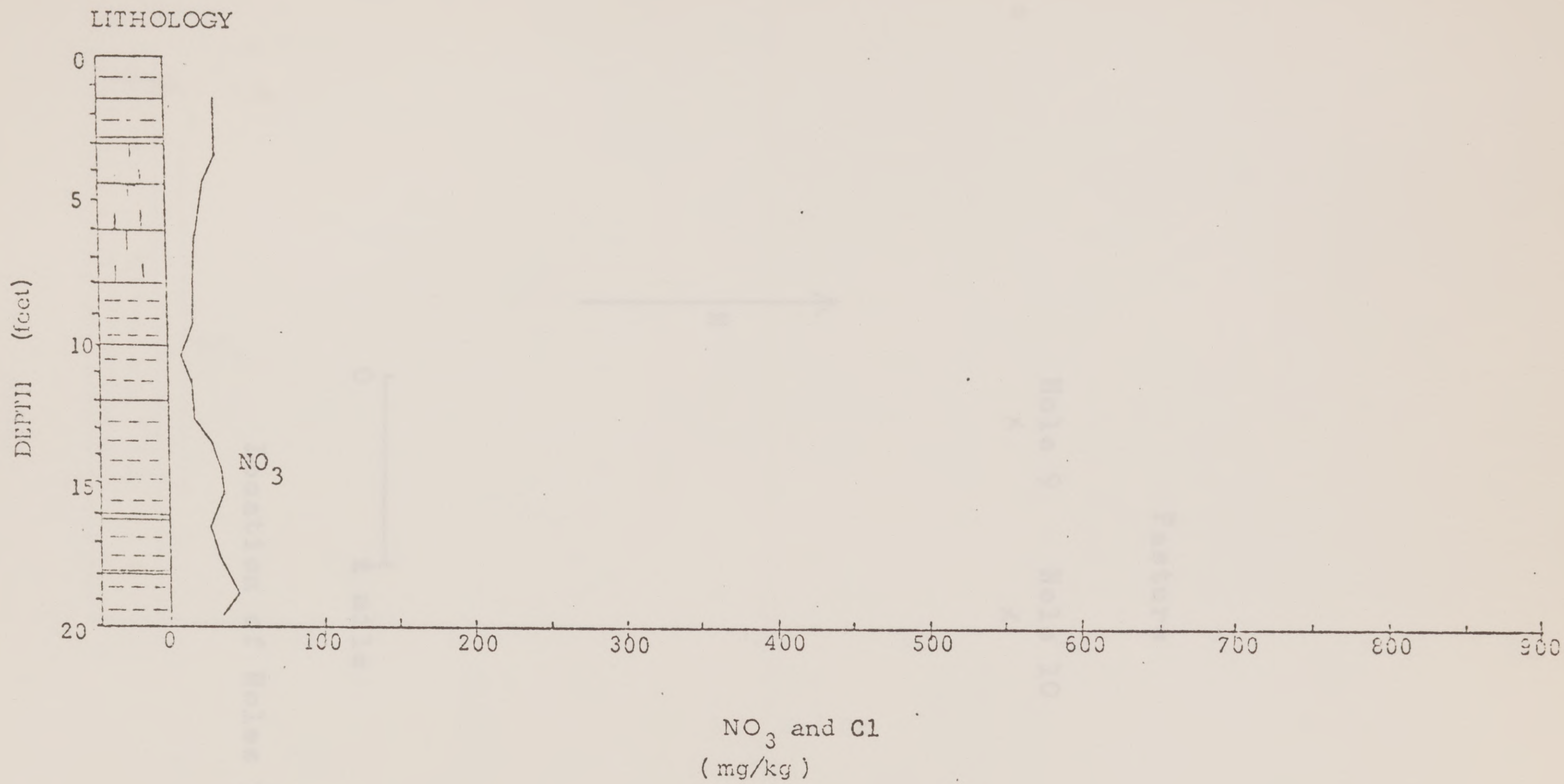
Location of Holes 7 and 8

Hole 9 and Hole 10

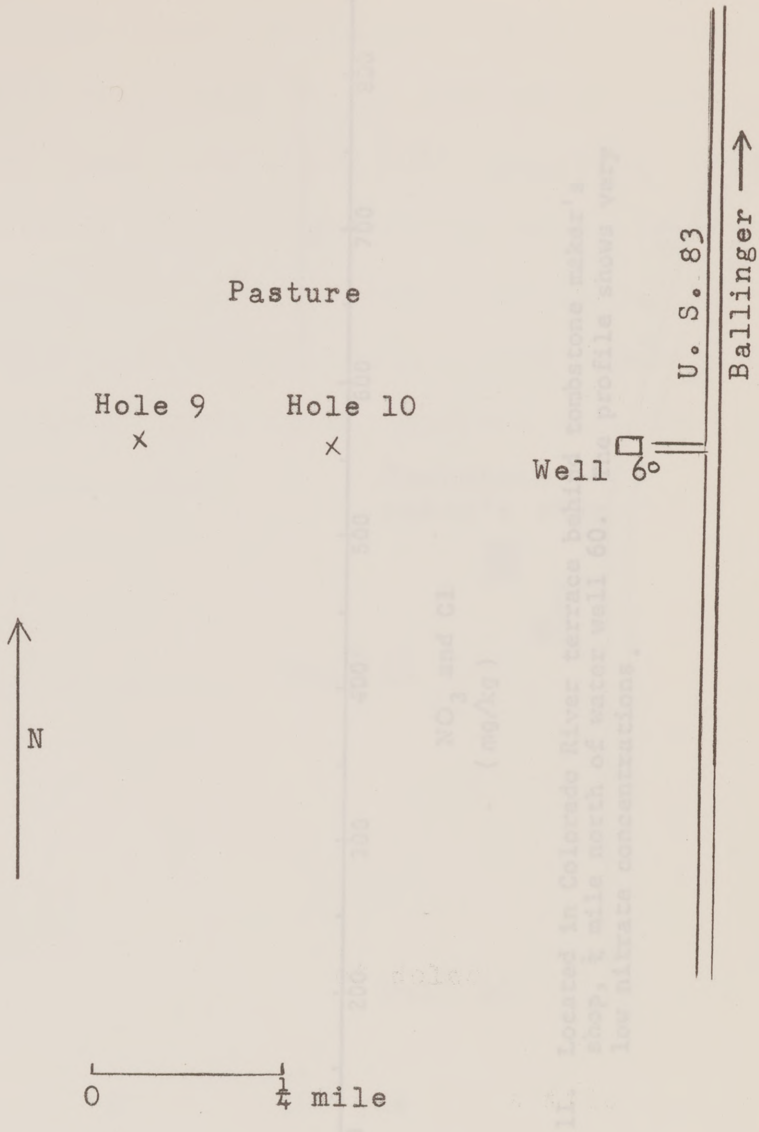
Hole 9 was drilled in a pasture on the top of a hill, 1/2 mile west of water well 6. Cattle were grazing in the area. There are no anomalous nitrate concentrations in this soil. Hole 10 was drilled in the same pasture as Hole 9, but only 1/4 mile west of water well 6 and the farm house. There are no abnormal nitrate concentrations in this soil either. The soils of this field are not a major source of contamination.



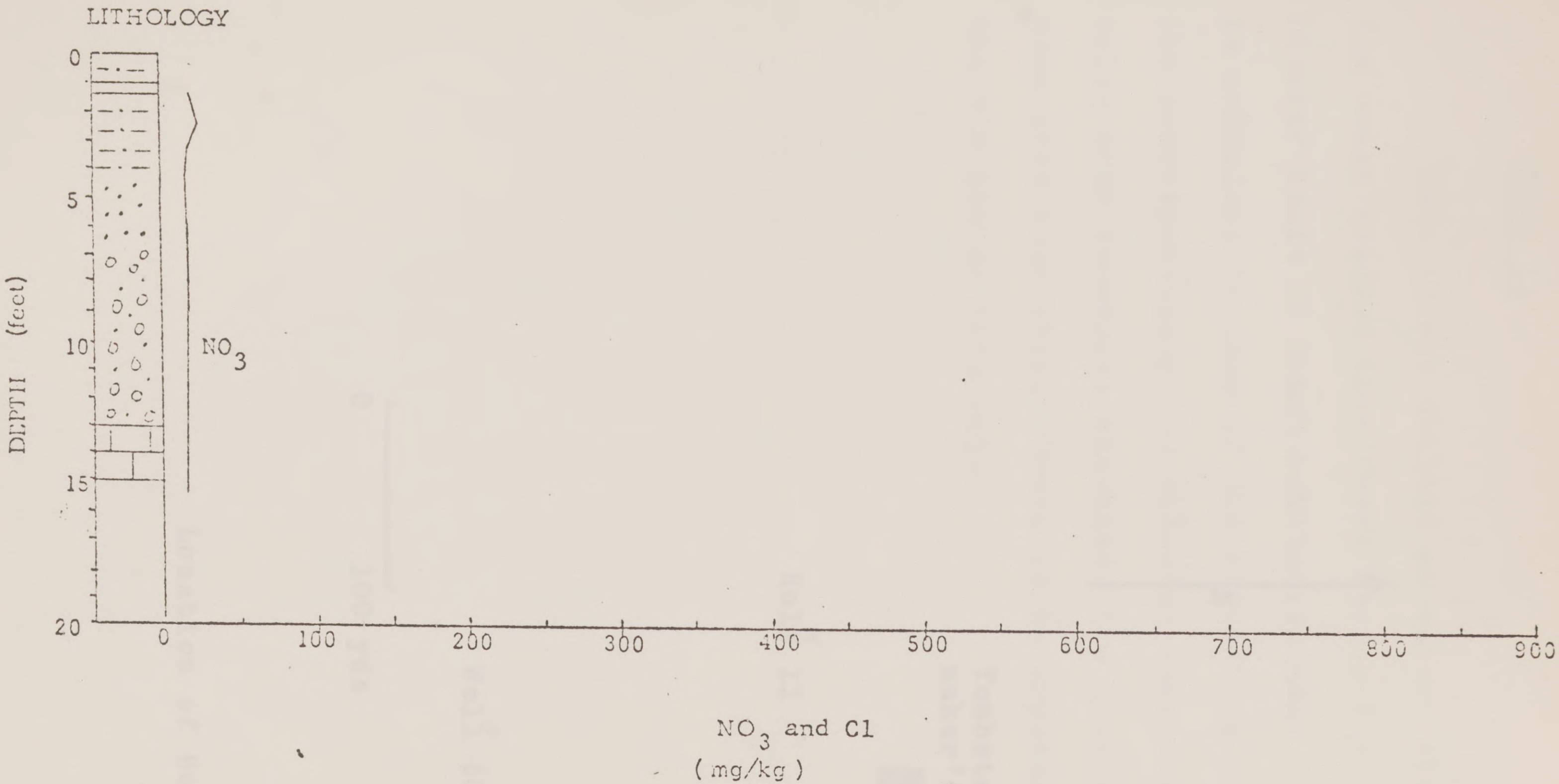
Hole 9. Located in a cattle pasture on the top of a hill, ½ mile west of water well 6 and human habitation.



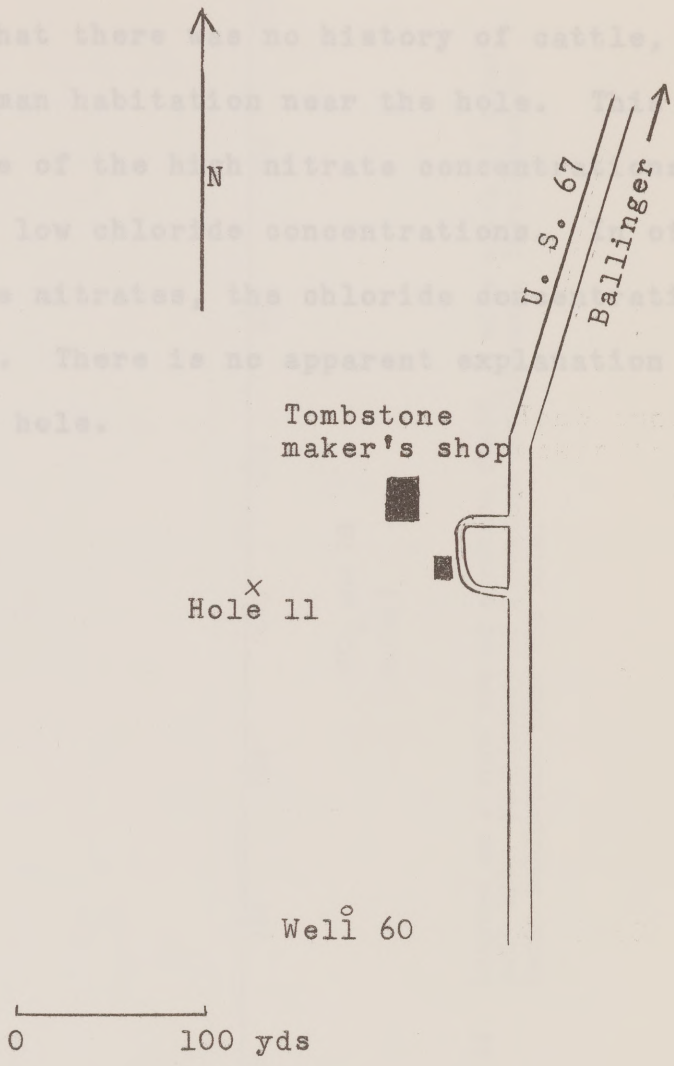
Hole 10. Located in the same cattle pasture as Hole 9 on the side of a hill in between two terraces and ¼ mile west of water well 6 and human habitation.



Location of Holes 9 and 10



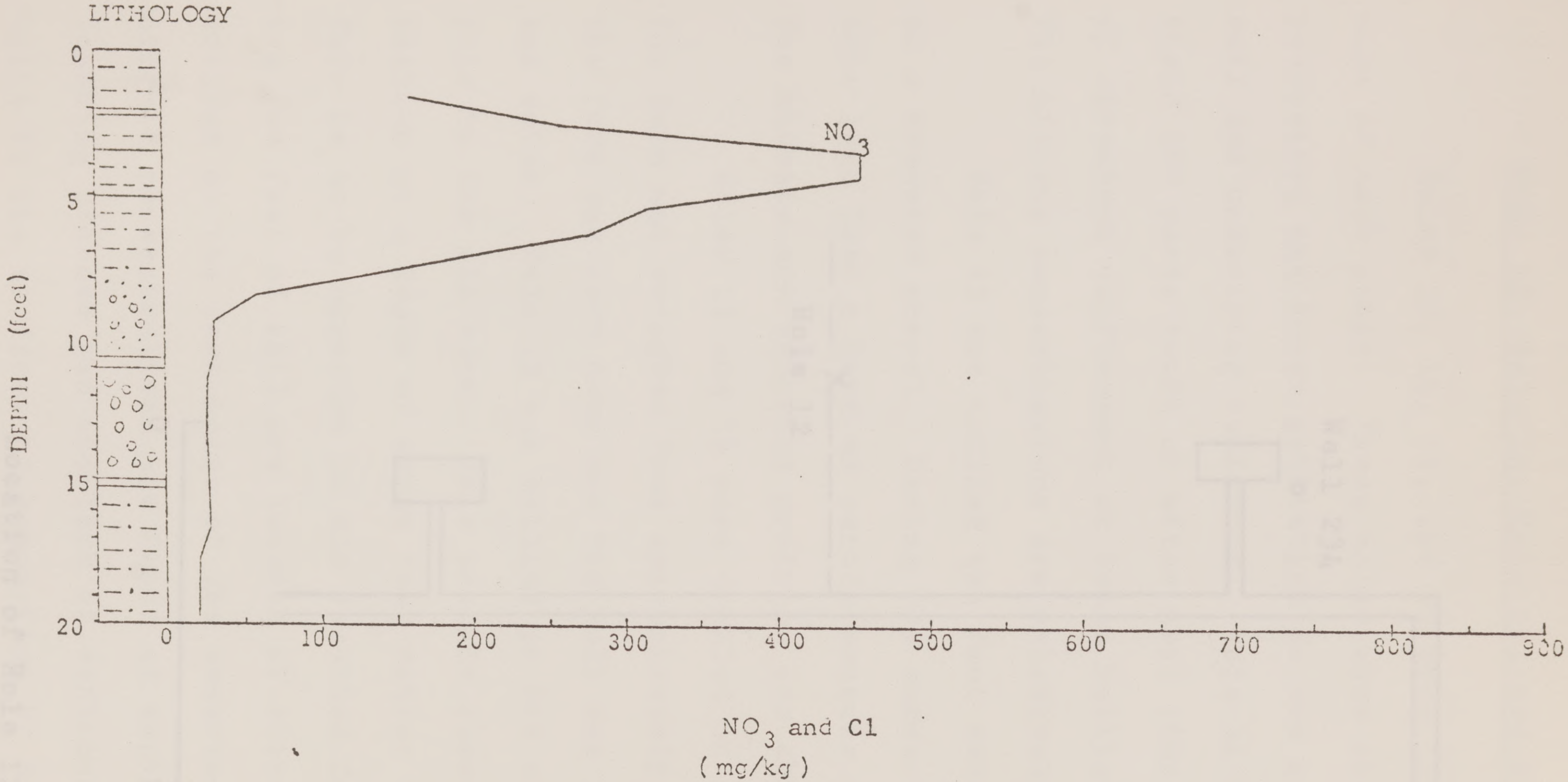
Hole 11. Located in Colorado River terrace behind tombstone maker's shop, ¼ mile north of water well 60. The profile shows very low nitrate concentrations.



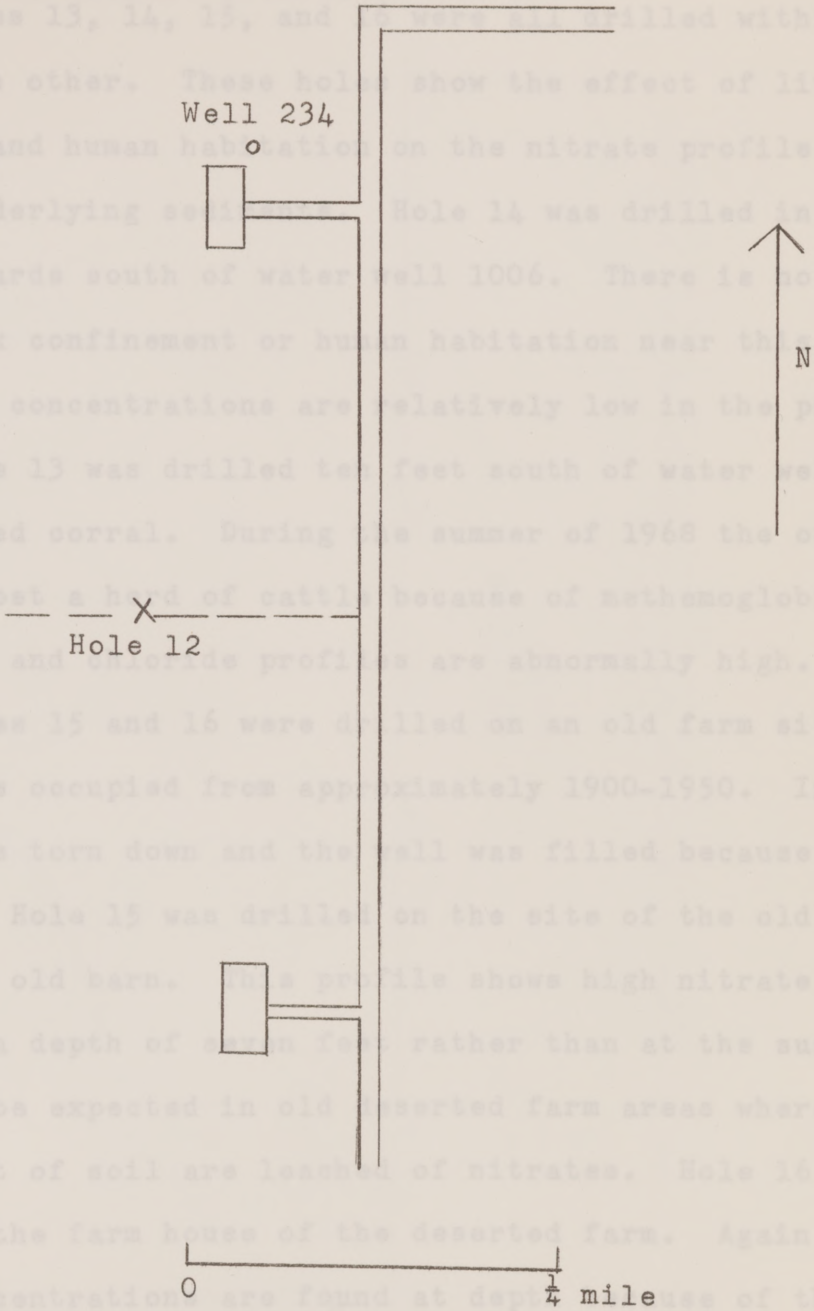
Location of Hole 11

Hole 12

Hole 12 was drilled on a turn row in a cotton field. The owner claimed that there was no history of cattle, fertilizer usage or human habitation near the hole. This hole is anomalous because of the high nitrate concentrations and the correspondingly low chloride concentrations. In other holes with excessive nitrates, the chloride concentrations have also been high. There is no apparent explanation for the nitrate at this hole.



Hole 12. Located on a turn row of a cotton field, ¼ mile south of water well 234. No history of livestock confinement, fertilizer or human habitation near the hole.



Location of Hole 12

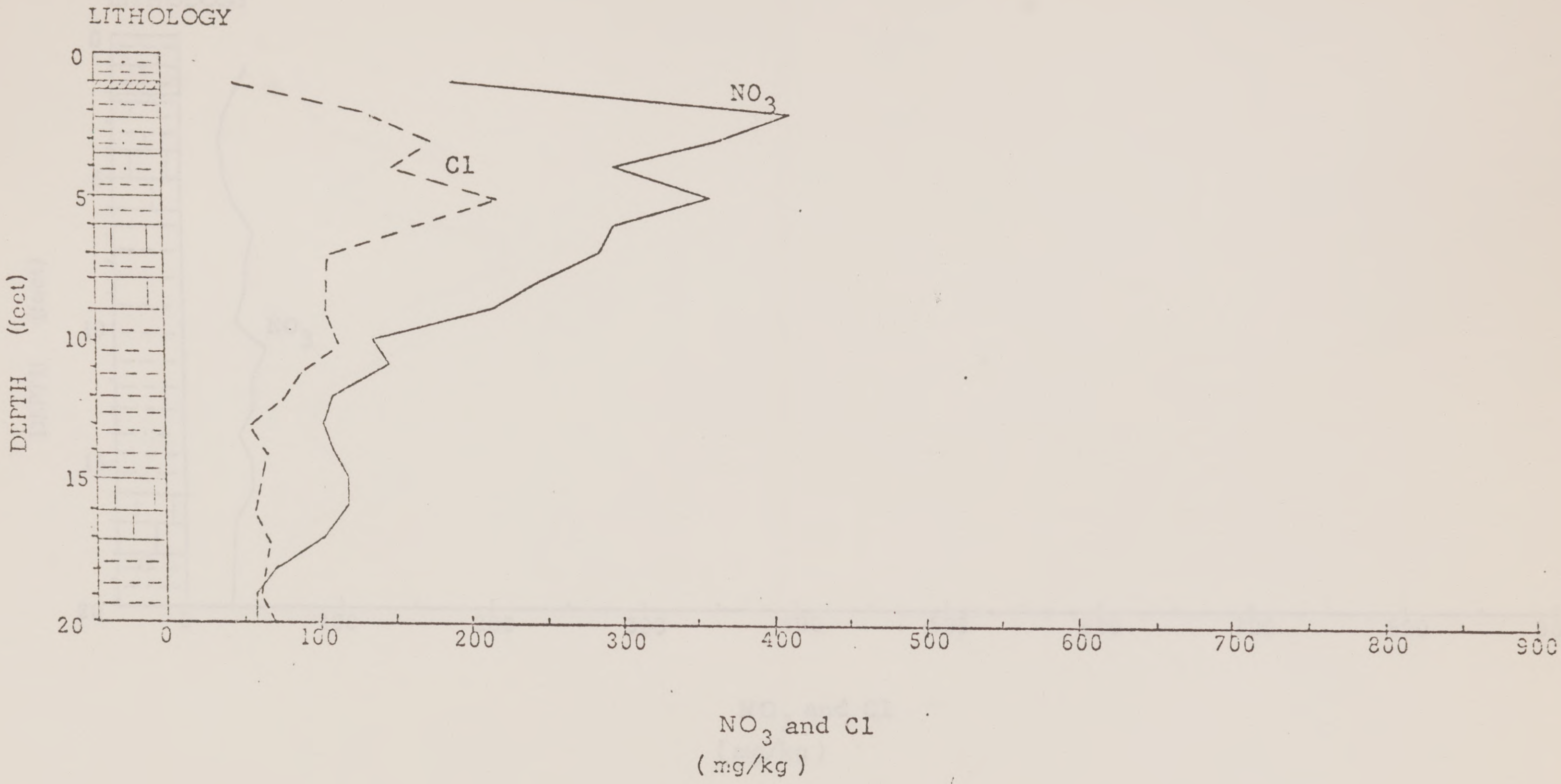
Hole 13, Hole 14, Hole 15, and Hole 16

Holes 13, 14, 15, and 16 were all drilled within 1/4 mile of each other. These holes show the effect of livestock production and human habitation on the nitrate profile of the soil and underlying sediments. Hole 14 was drilled in a maize field 100 yards south of water well 1006. There is no history of livestock confinement or human habitation near this hole. The nitrate concentrations are relatively low in the profile.

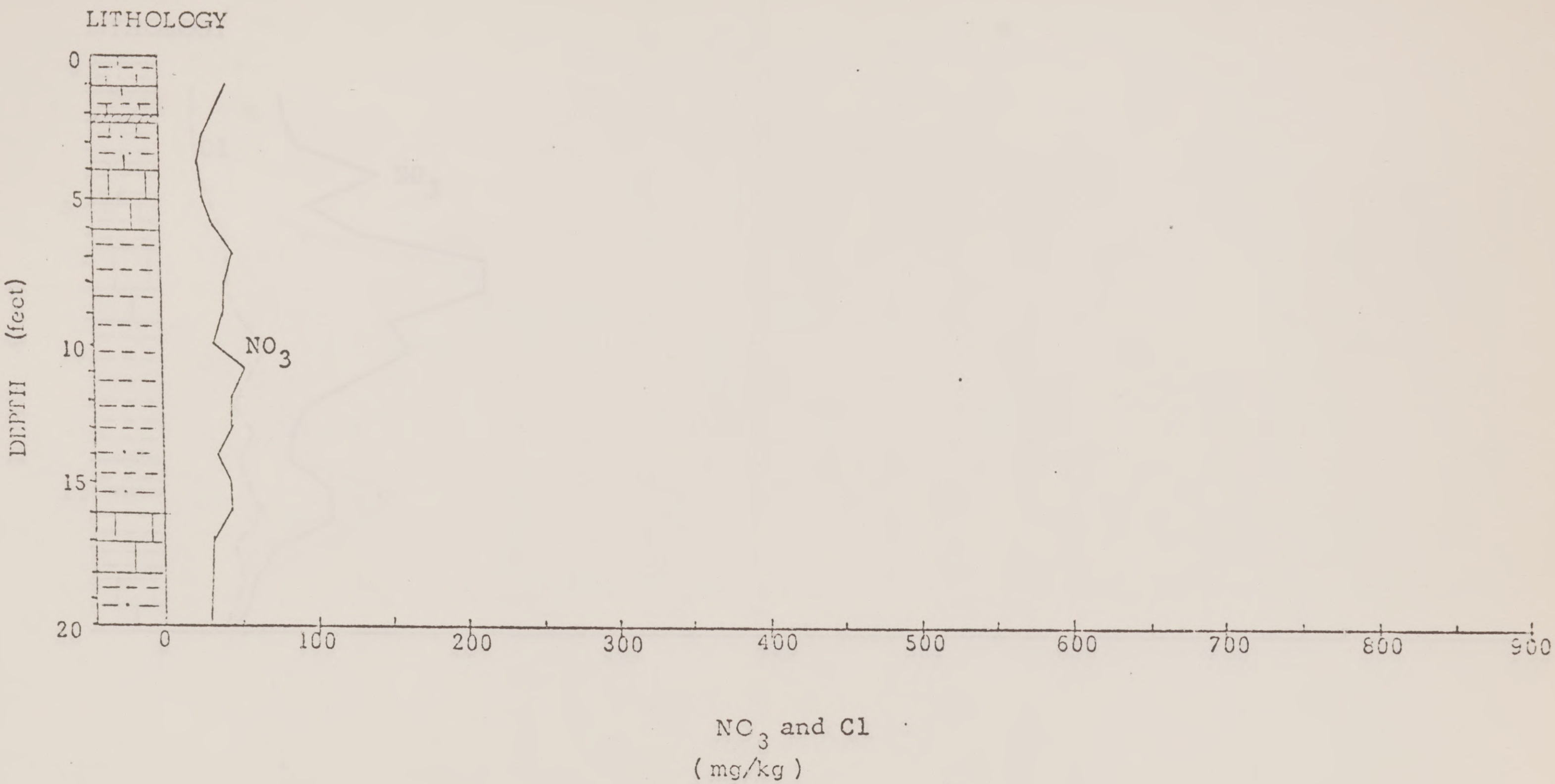
Hole 13 was drilled ten feet south of water well 1006 at a deserted corral. During the summer of 1968 the owner of this land lost a herd of cattle because of methemoglobinemia. The nitrate and chloride profiles are abnormally high.

Holes 15 and 16 were drilled on an old farm site. The farm was occupied from approximately 1900-1950. In 1950 the farm was torn down and the well was filled because of its bad water. Hole 15 was drilled on the site of the old manure pile in the old barn. This profile shows high nitrate concentration at a depth of seven feet rather than at the surface. This is to be expected in old deserted farm areas where the top few feet of soil are leached of nitrates. Hole 16 was drilled at the farm house of the deserted farm. Again high nitrate concentrations are found at depth because of the leaching process and the lack of continual addition of nitrate to the surface. A comparison of Holes 13, 14, 15, and

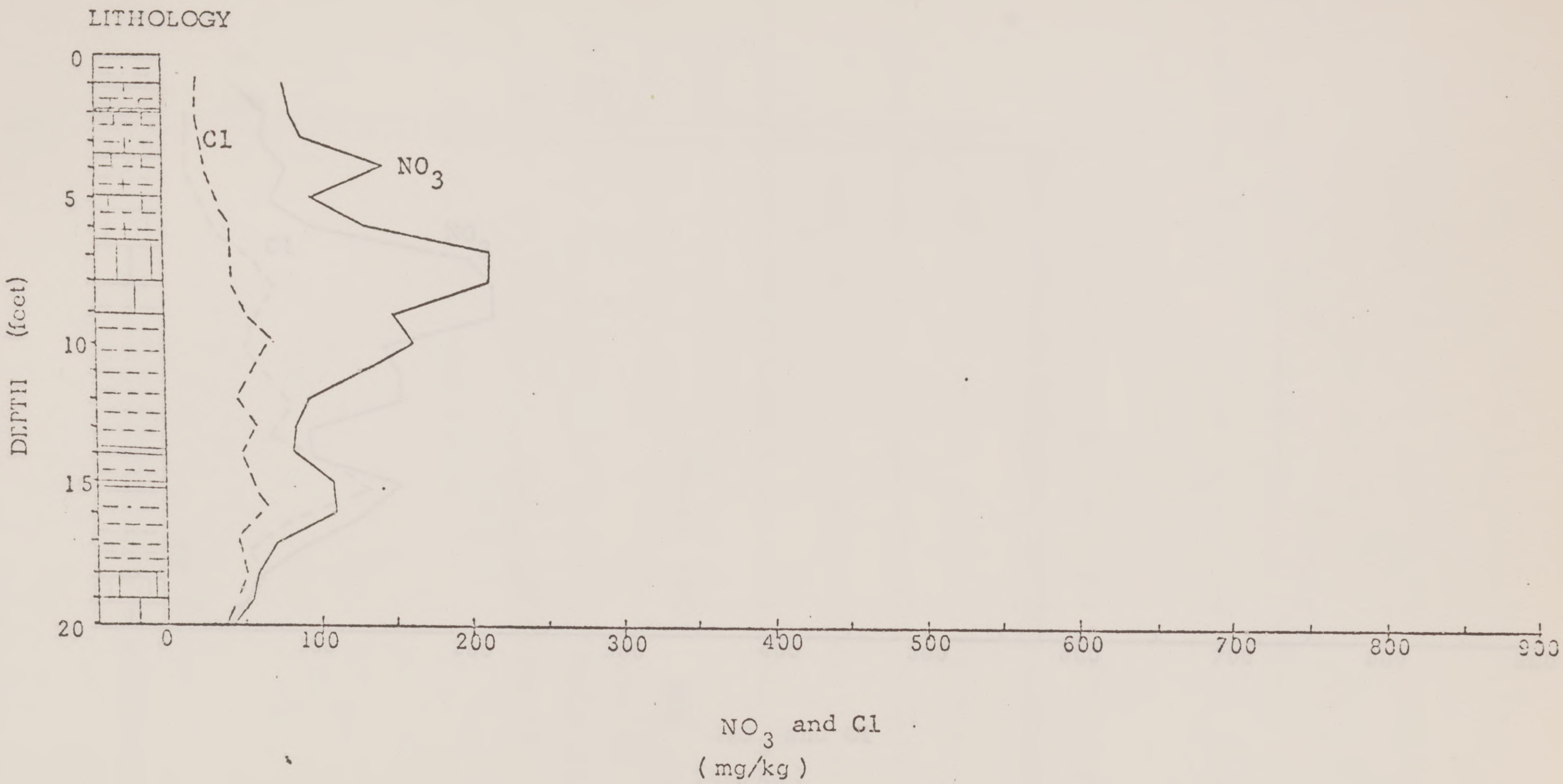
16 shows the effect of animal husbandry and human habitation on the natural nitrate profile of the soil.



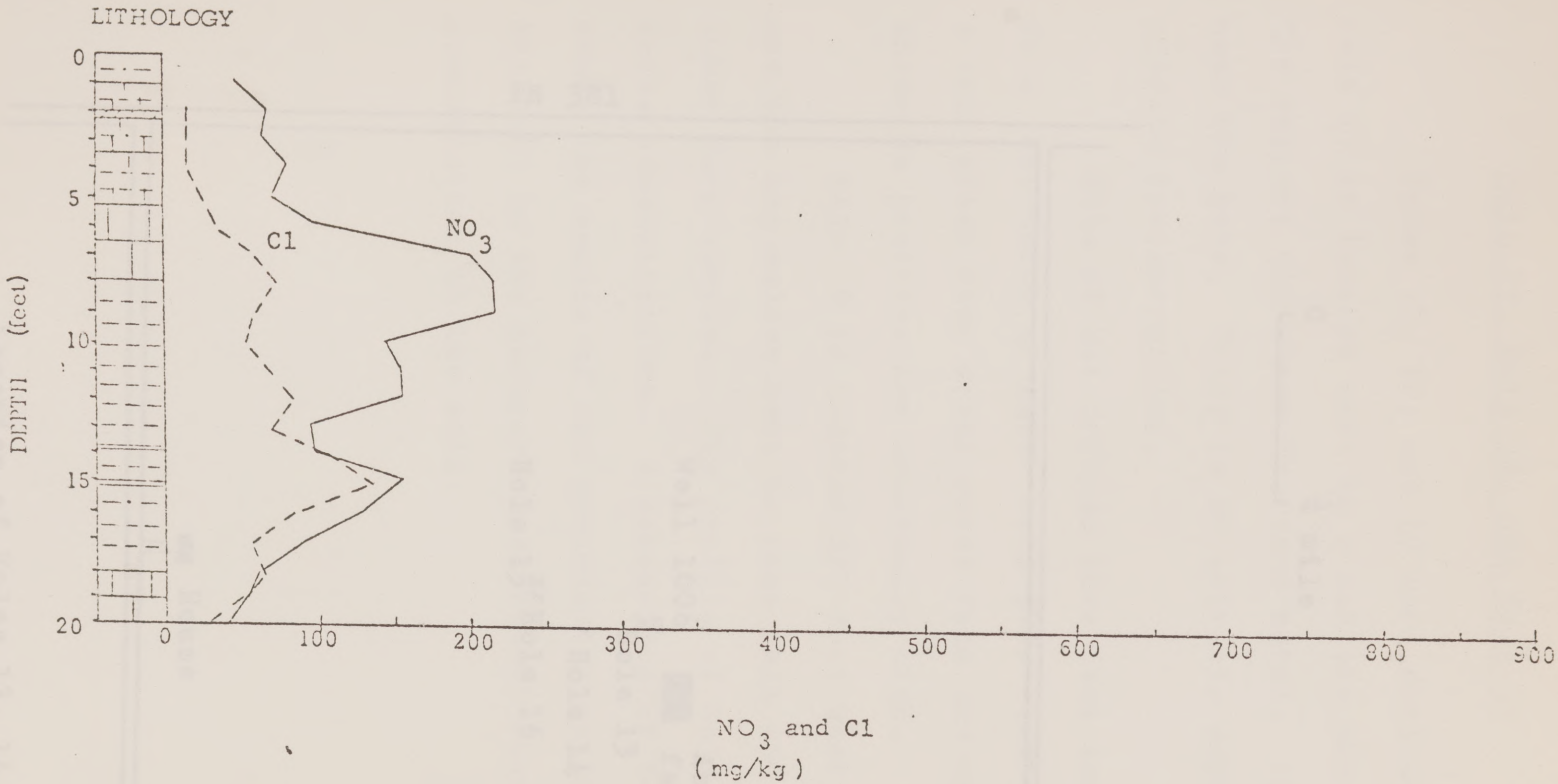
Hole 13. Located 10 feet south of deserted barnyard and water well 1006. Herd of cattle died from drinking the water from well 1006.



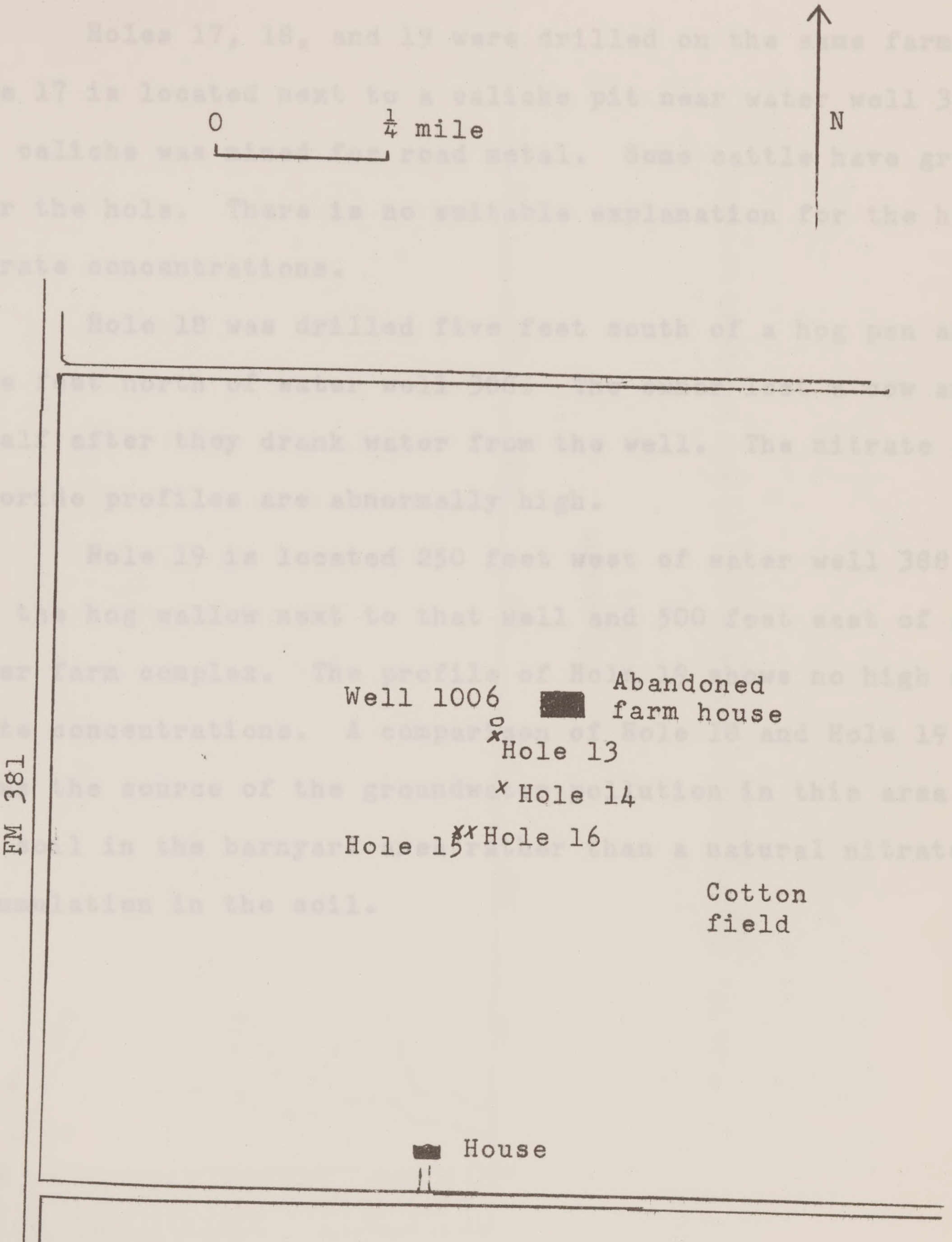
Hole 14. Located in a maize field, 100 yards south of water well 1006. No history of livestock confinement, fertilizer or human habitation near the hole.



Hole 15. Located on site of torn-down barn of old farm, 250 yards south of water well 1006.



Hole 16. Located on site of torn-down house of old farm, 250 yards south of water well 1006.



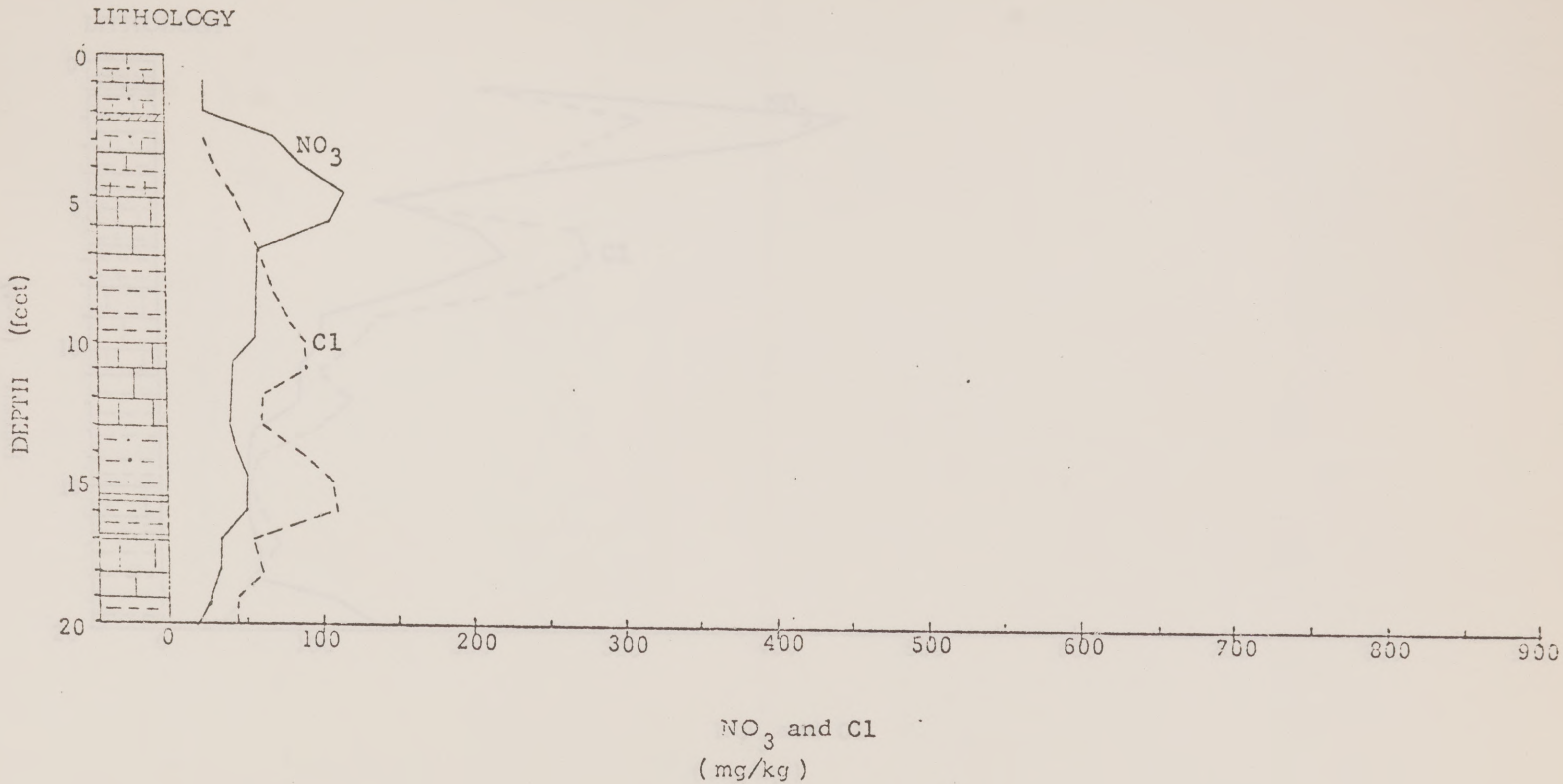
Location of Holes 13, 14, 15, and 16

Hole 17, Hole 18, and Hole 19

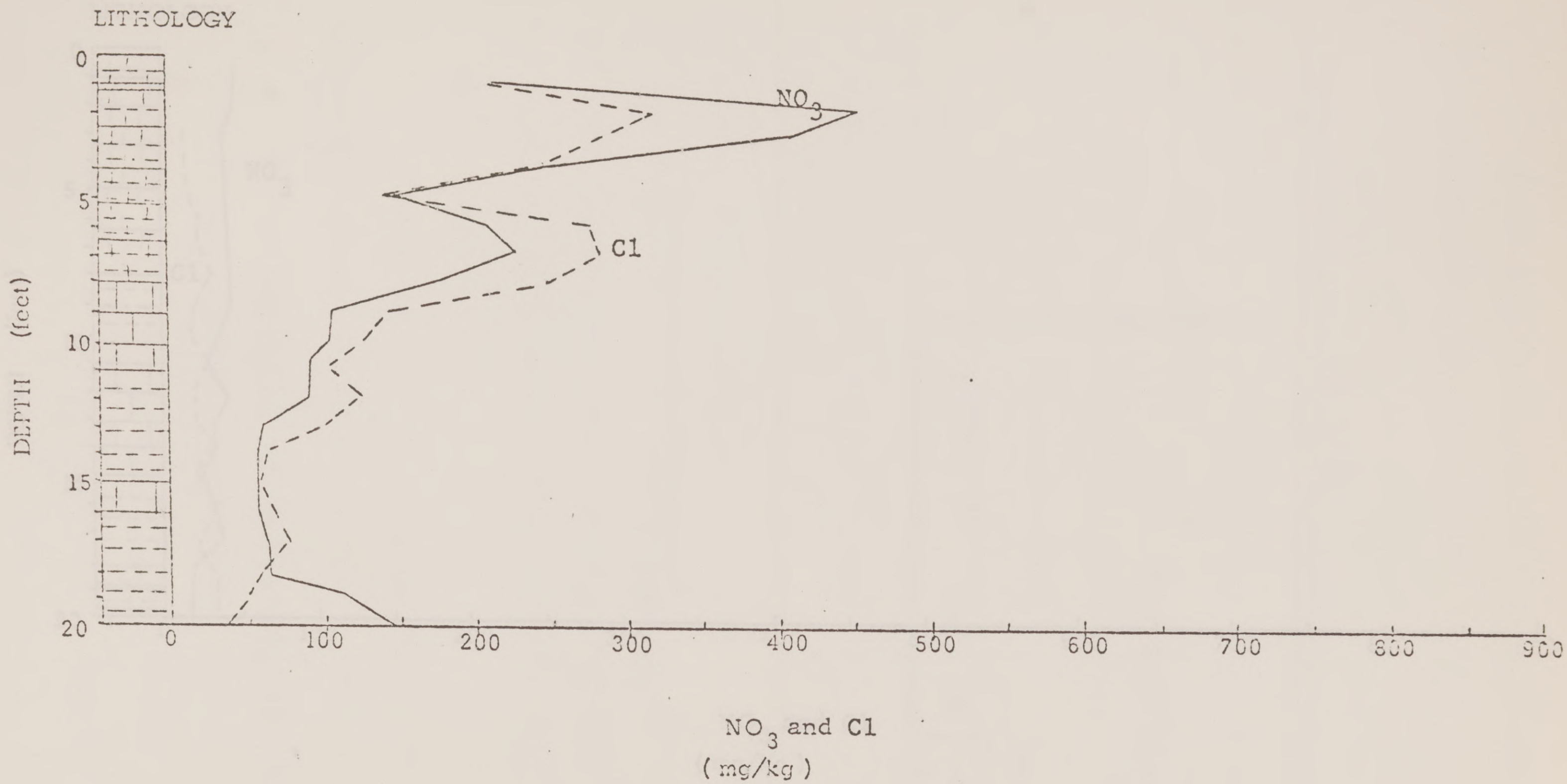
Holes 17, 18, and 19 were drilled on the same farm. Hole 17 is located next to a caliche pit near water well 386. The caliche was mined for road metal. Some cattle have grazed near the hole. There is no suitable explanation for the high nitrate concentrations.

Hole 18 was drilled five feet south of a hog pen and five feet north of water well 388. The owner lost a cow and a calf after they drank water from the well. The nitrate and chloride profiles are abnormally high.

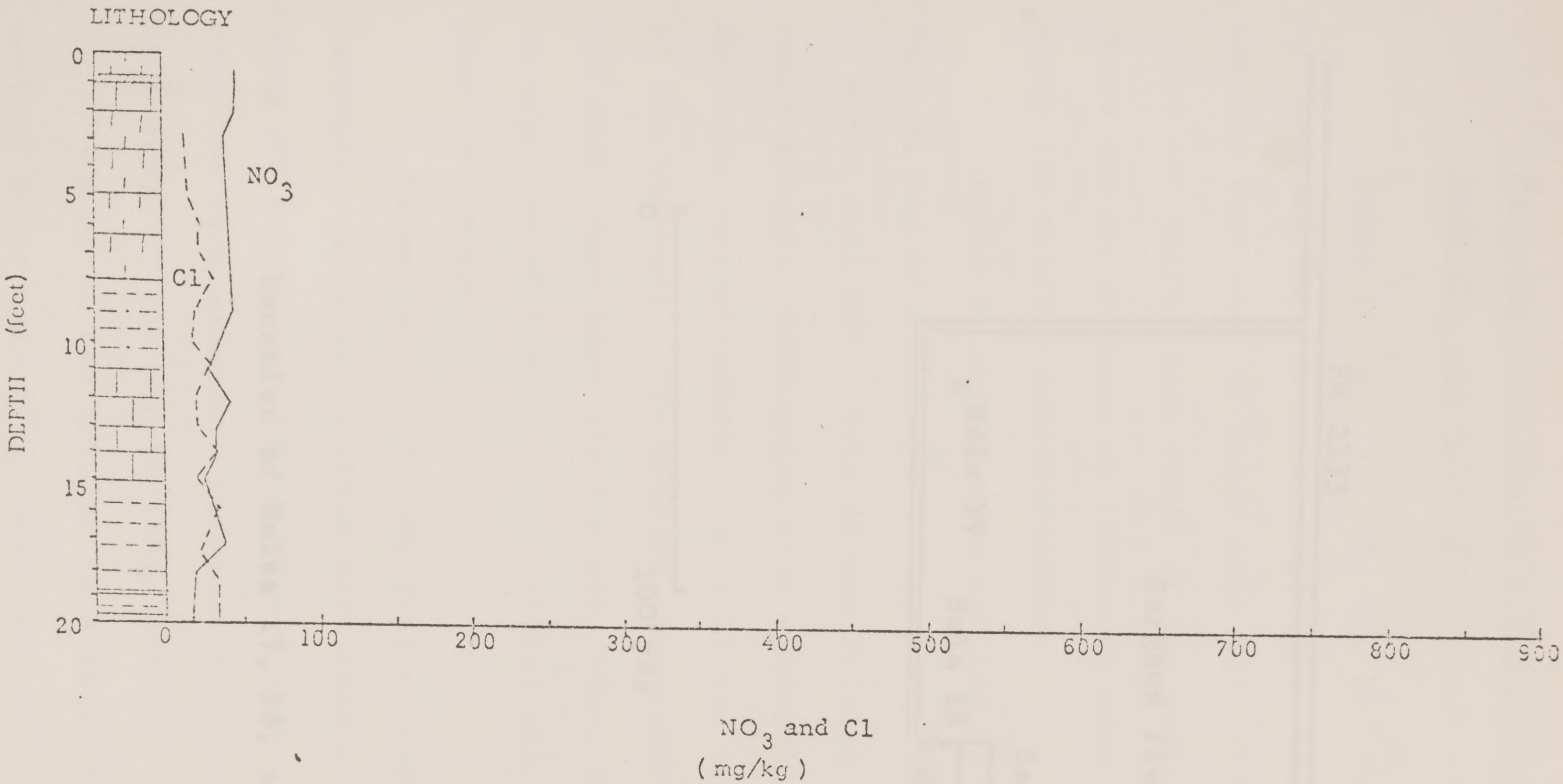
Hole 19 is located 250 feet west of water well 388 and the hog wallow next to that well and 500 feet east of another farm complex. The profile of Hole 19 shows no high nitrate concentrations. A comparison of Hole 18 and Hole 19 shows the source of the groundwater pollution in this area is the soil in the barnyard area rather than a natural nitrate accumulation in the soil.



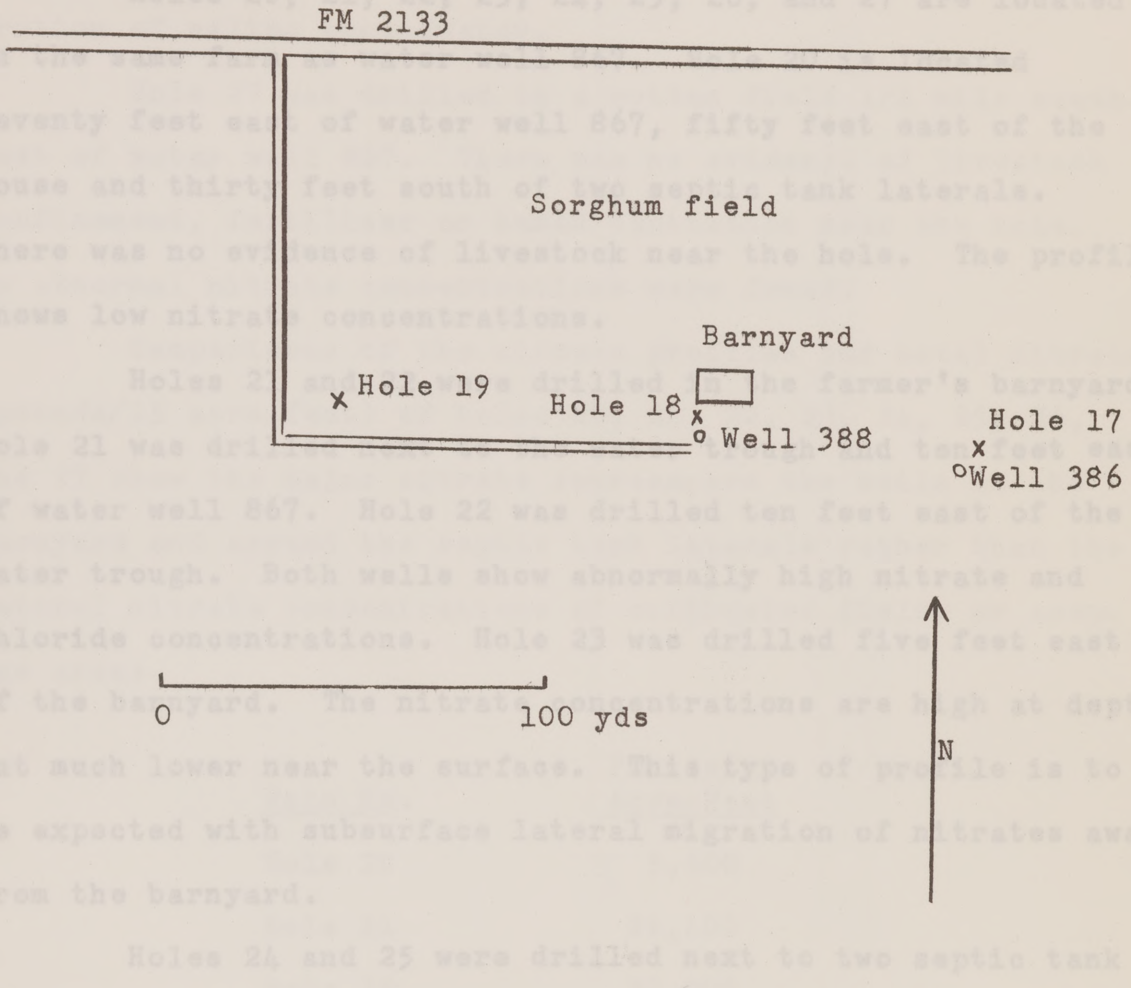
Hole 17. Located next to a caliche pit, 30 feet southeast of water well 386. History of a few cattle.



Hole 18. Located 5 feet south of a hog pen and 5 feet north of water well 388.



Hole 19. Located in a cotton field, 250 feet west of water well 388. No history of livestock confinement, fertilizer or human habitation near the hole.



Location of Holes 17, 18, and 19

<u>Hole 20, Hole 21, Hole 22, Hole 23, Hole 24, Hole 25, Hole 26, and Hole 27</u>

Holes 20, 21, 22, 23, 24, 25, 26, and 27 are located on the same farm as water well 867. Hole 20 is located seventy feet east of water well 867, fifty feet east of the house and thirty feet south of two septic tank laterals. There was no evidence of livestock near the hole. The profile shows low nitrate concentrations.

Holes 21 and 22 were drilled in the farmer's barnyard. Hole 21 was drilled next to the water trough and ten feet east of water well 867. Hole 22 was drilled ten feet east of the water trough. Both wells show abnormally high nitrate and chloride concentrations. Hole 23 was drilled five feet east of the barnyard. The nitrate concentrations are high at depth, but much lower near the surface. This type of profile is to be expected with subsurface lateral migration of nitrates away from the barnyard.

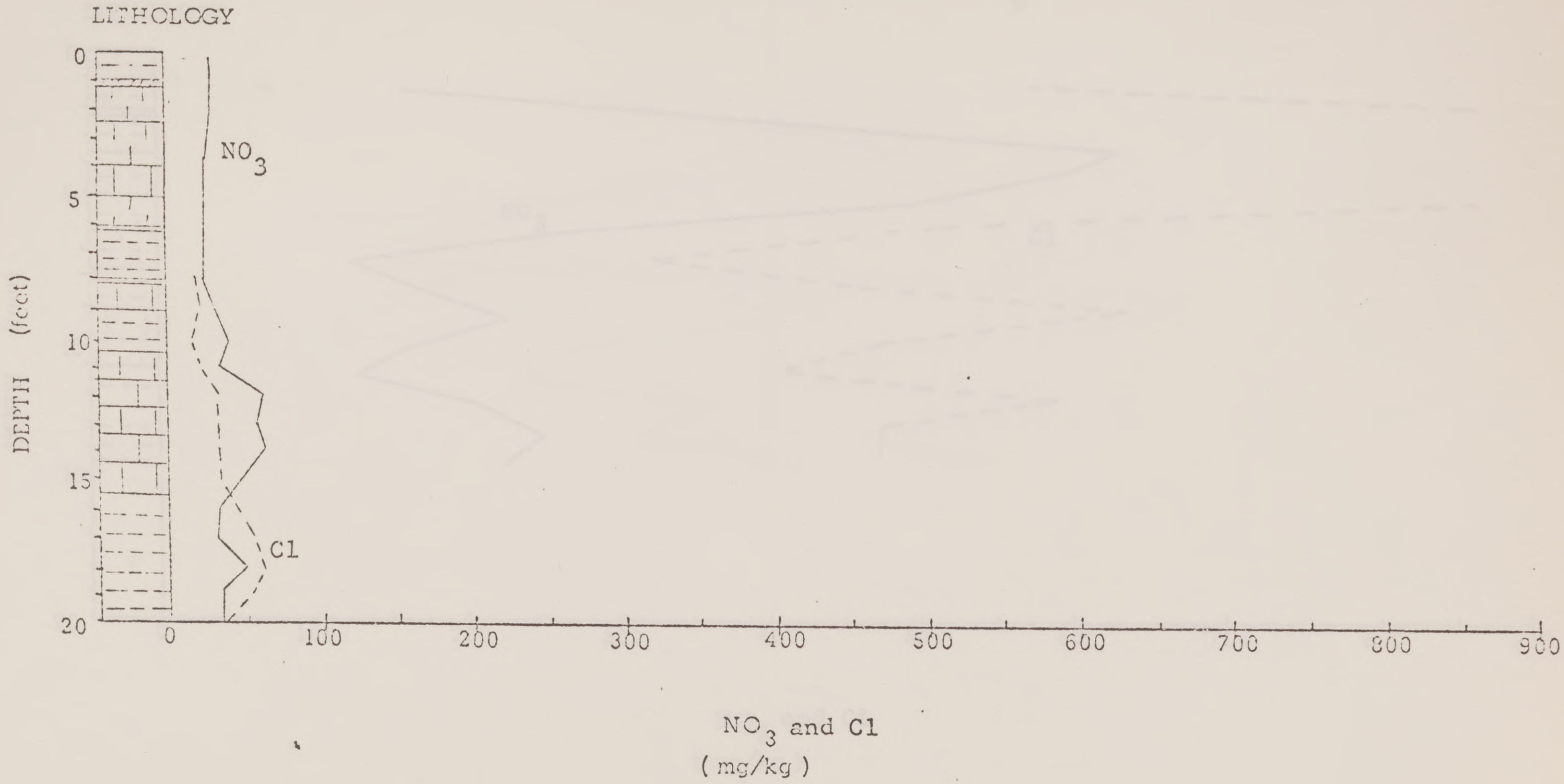
Holes 24 and 25 were drilled next to two septic tank laterals. Hole 24 is three feet from a new septic tank lateral and ten feet south of an old septic tank lateral. Both profiles show excessive nitrates at three feet, the approximate depth of the septic tank laterals.

Hole 26 was drilled in a seepage area 1/4 mile southeast of water well 867. There was no evidence of livestock confinement, fertilizer or human habitation near the hole. The high nitrate and chloride concentrations at the surface are probably caused by the accumulation of salts by the evaporation of saline groundwater.

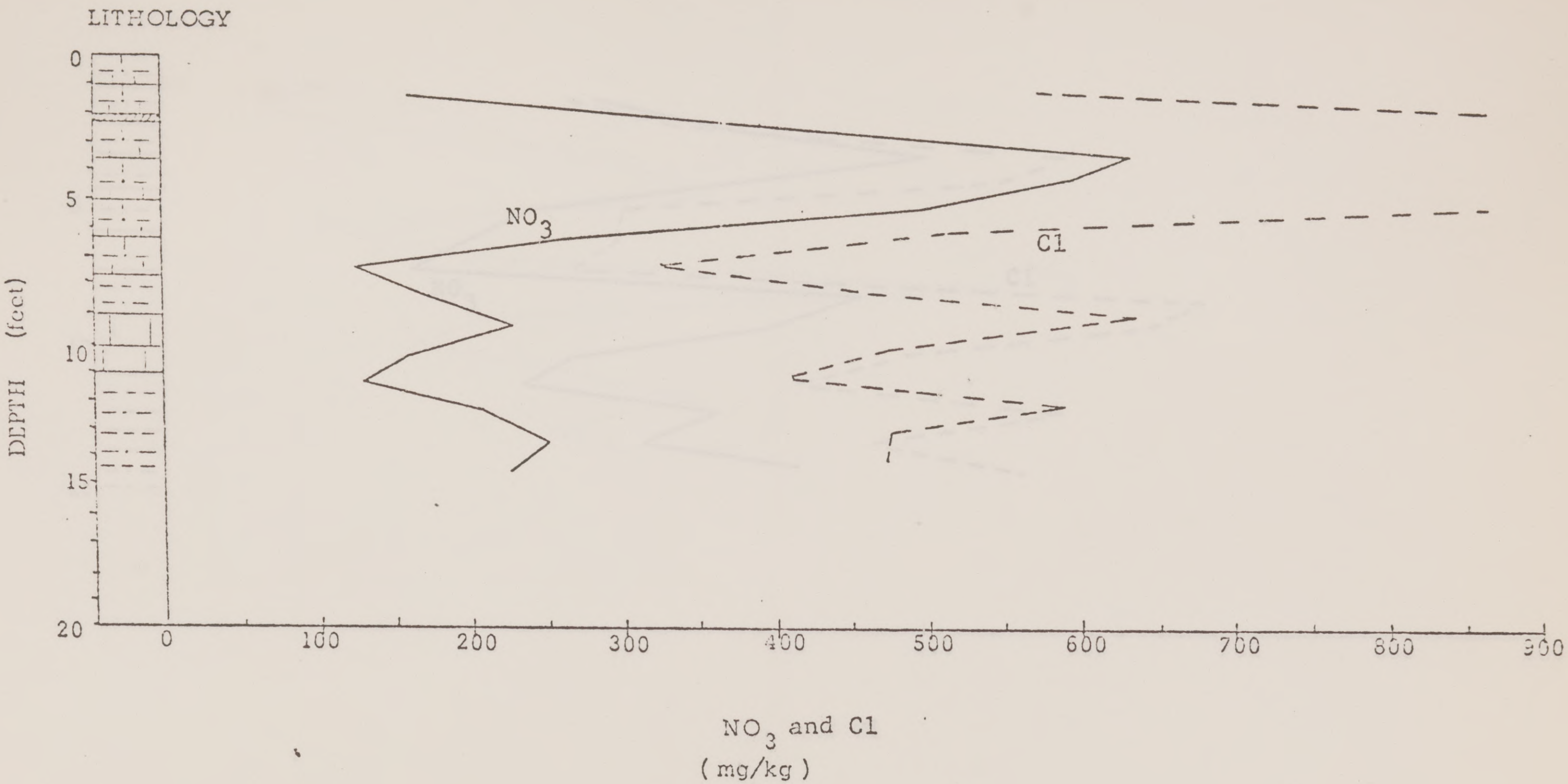
Hole 27 was drilled in a cotton field 1/4 mile southwest of water well 867. There was no evidence of livestock confinement, fertilizer or human habitation near the hole. No abnormal nitrate concentrations were found.

Comparisons of the nitrate profiles and total nitrate (pounds/15 acre-feet) of holes 20, 21, 22, 23, 24, 25, 26, and 27 show the major nitrate sources are the soils in the barnyard and around the septic tank laterals rather than the natural nitrate concentrations of cultivated fields or seepage areas.

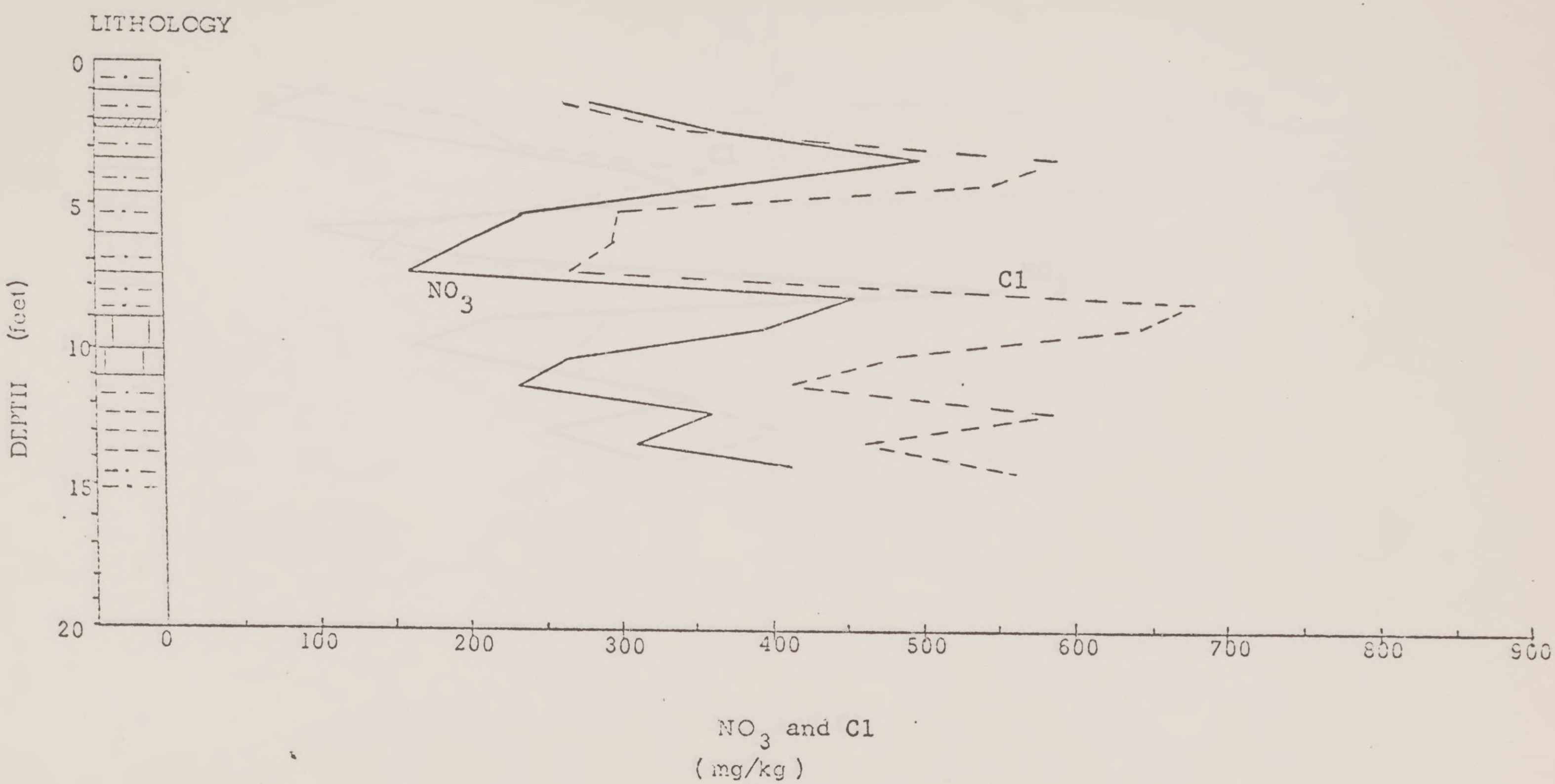
Hole No.	Pounds/15 Acre-Feet
Hole 20	3,600
Hole 21	26,100
Hole 22	30,000
Hole 23	16,000
Hole 24	32,000
Hole 25	16,600
Hole 26	6,000
Hole 27	3,200



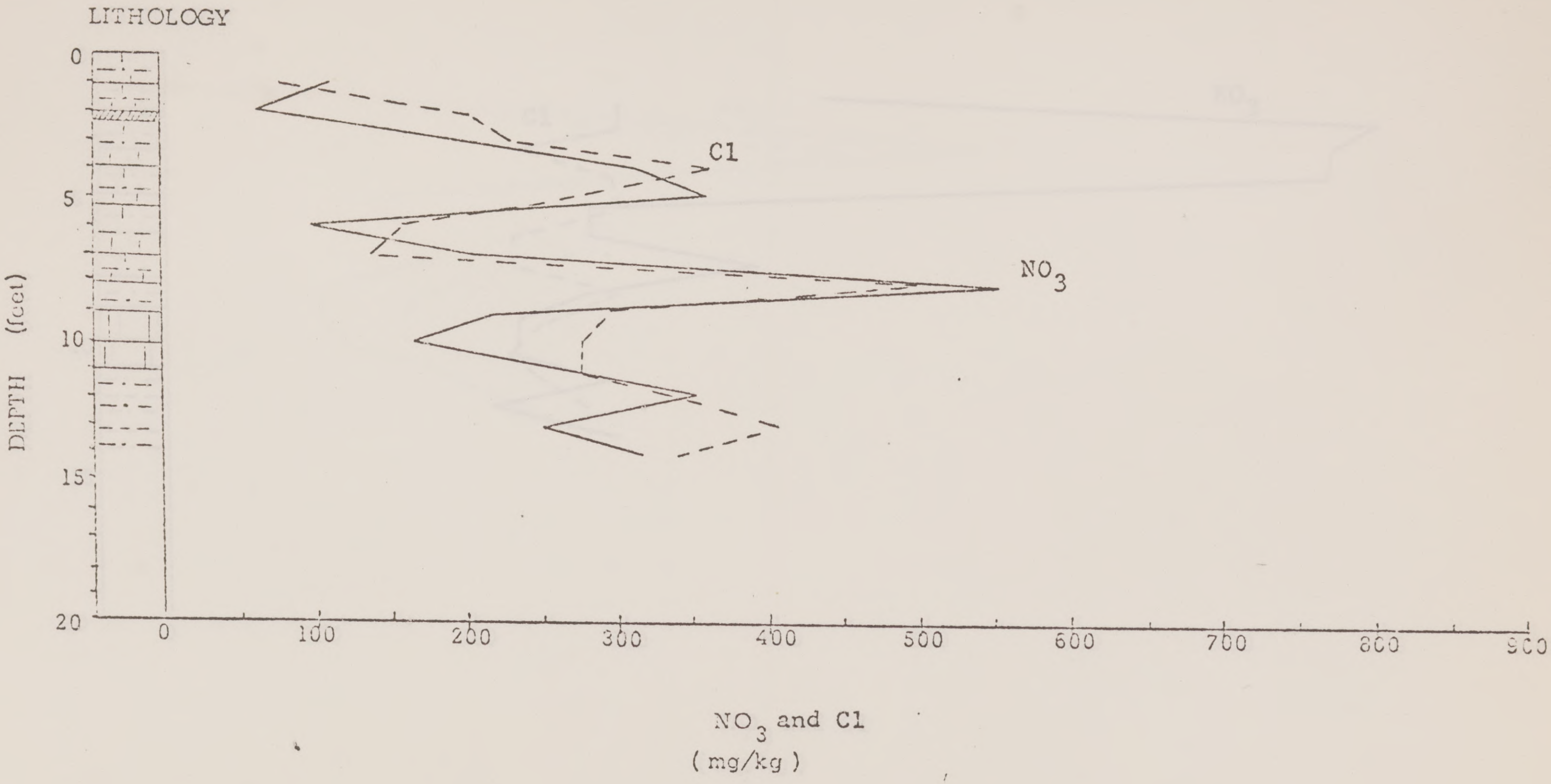
Hole 20. Located 50 feet east of a house and 70 feet east of water well 867. No history of livestock confinement, fertilizer or human habitation near the hole.



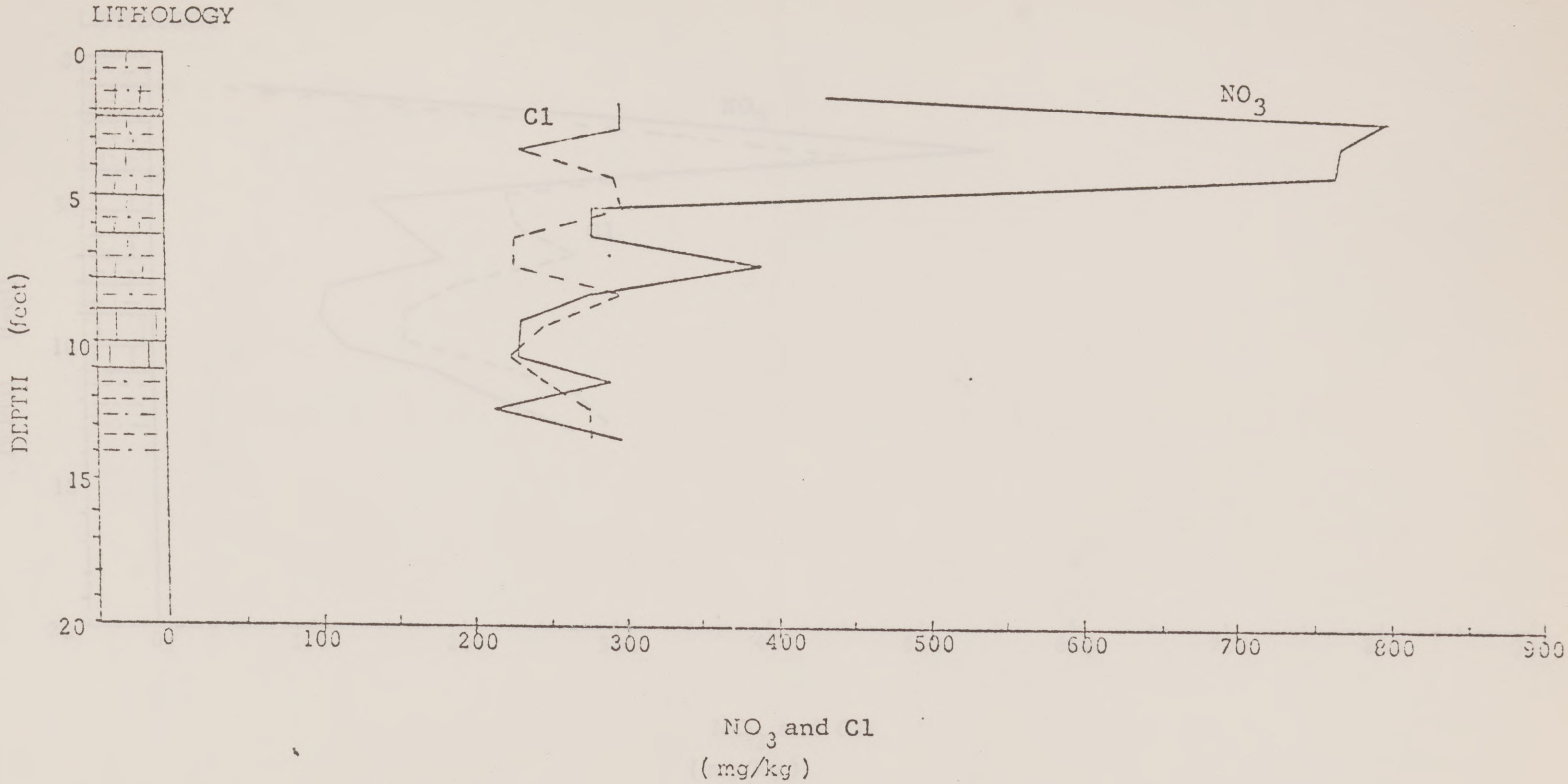
Hole 21. Located next to a water trough in a barnyard and 10 feet east of water well 867.



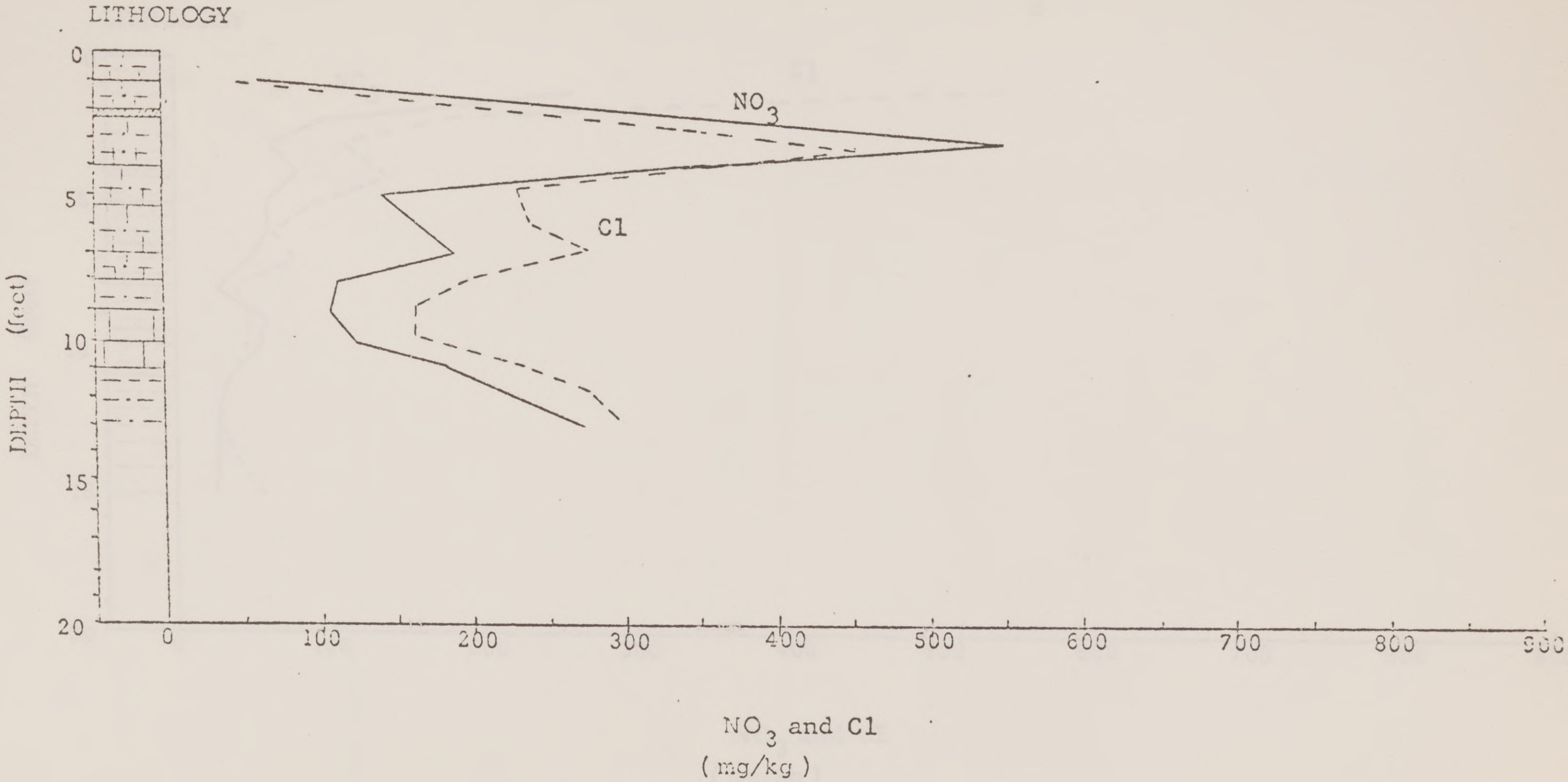
Hole 22. Located in the same barnyard as Hole 21, and 20 feet east of water well 867.



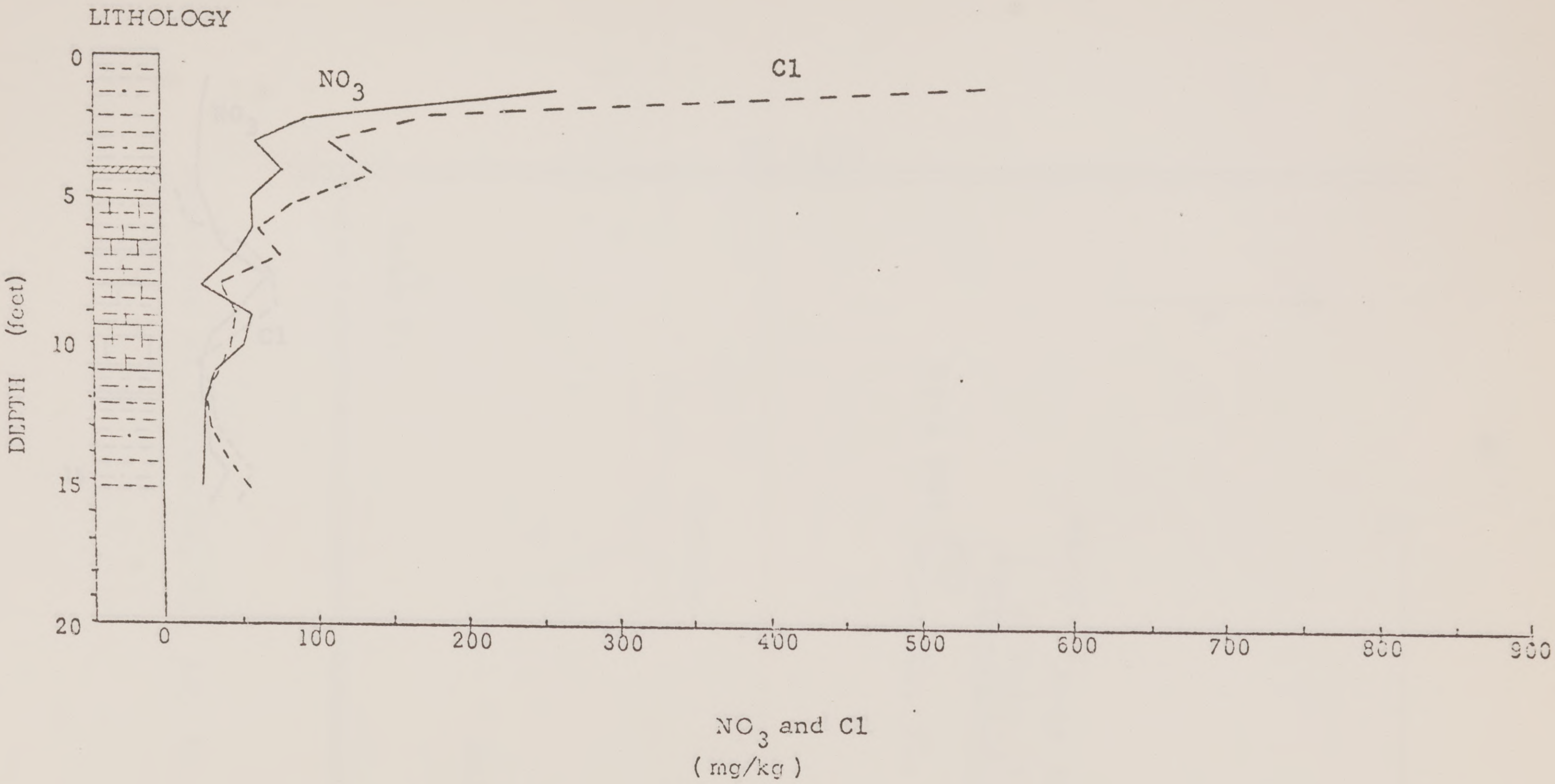
Hole 23. Located 5 feet outside the barnyard and 30 feet east of water well 867.



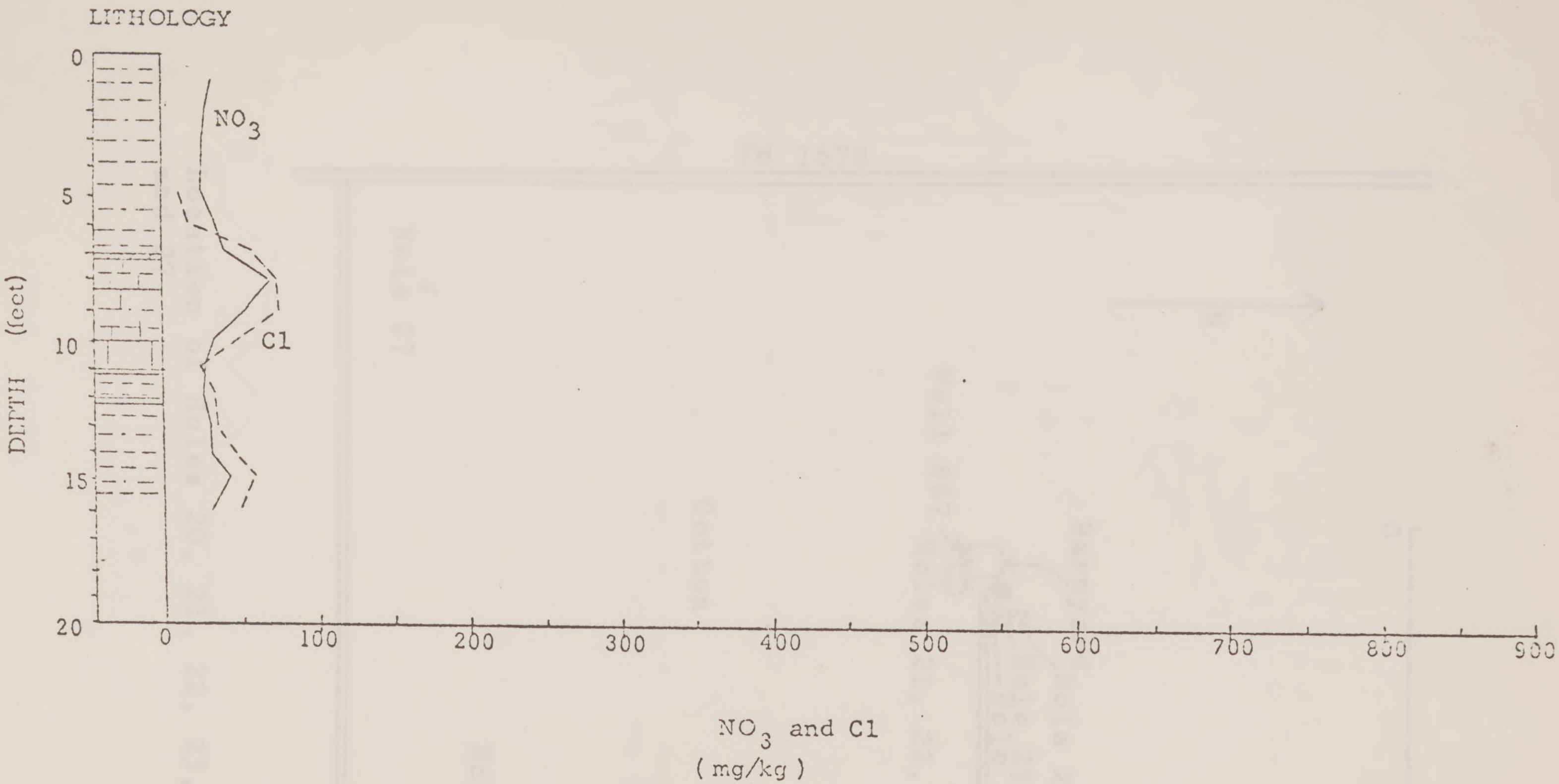
Hole 24. Located 2 feet south of new septic tank lateral and 55 feet northeast of water well 867.



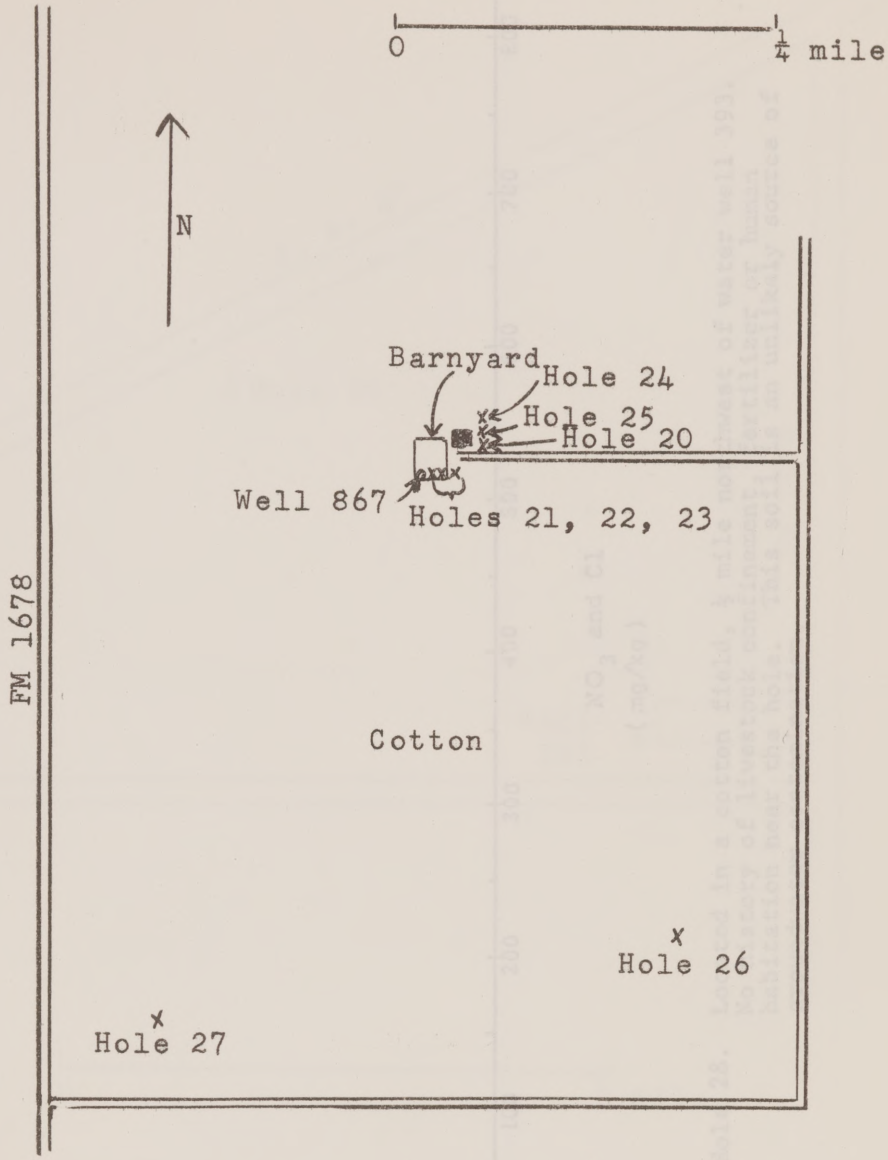
Hole 25. Located 2 feet east of old septic tank lateral, 10 feet south of Hole 24 and 50 feet northeast of water well 867.



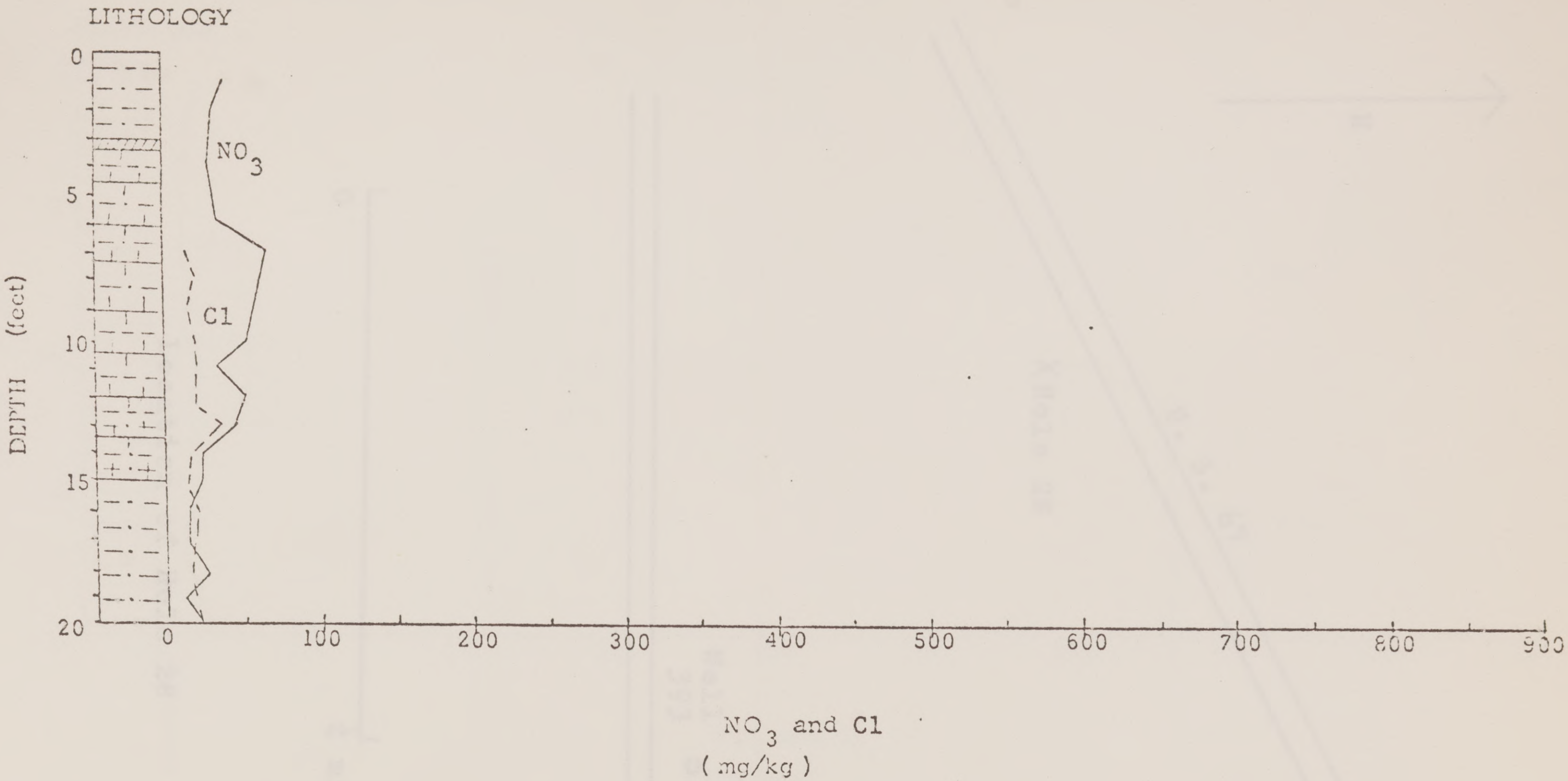
Hole 26. Located in seep area, ¼ mile southeast of water well 867. No history of livestock confinement, fertilizer or human habitation near the hole.



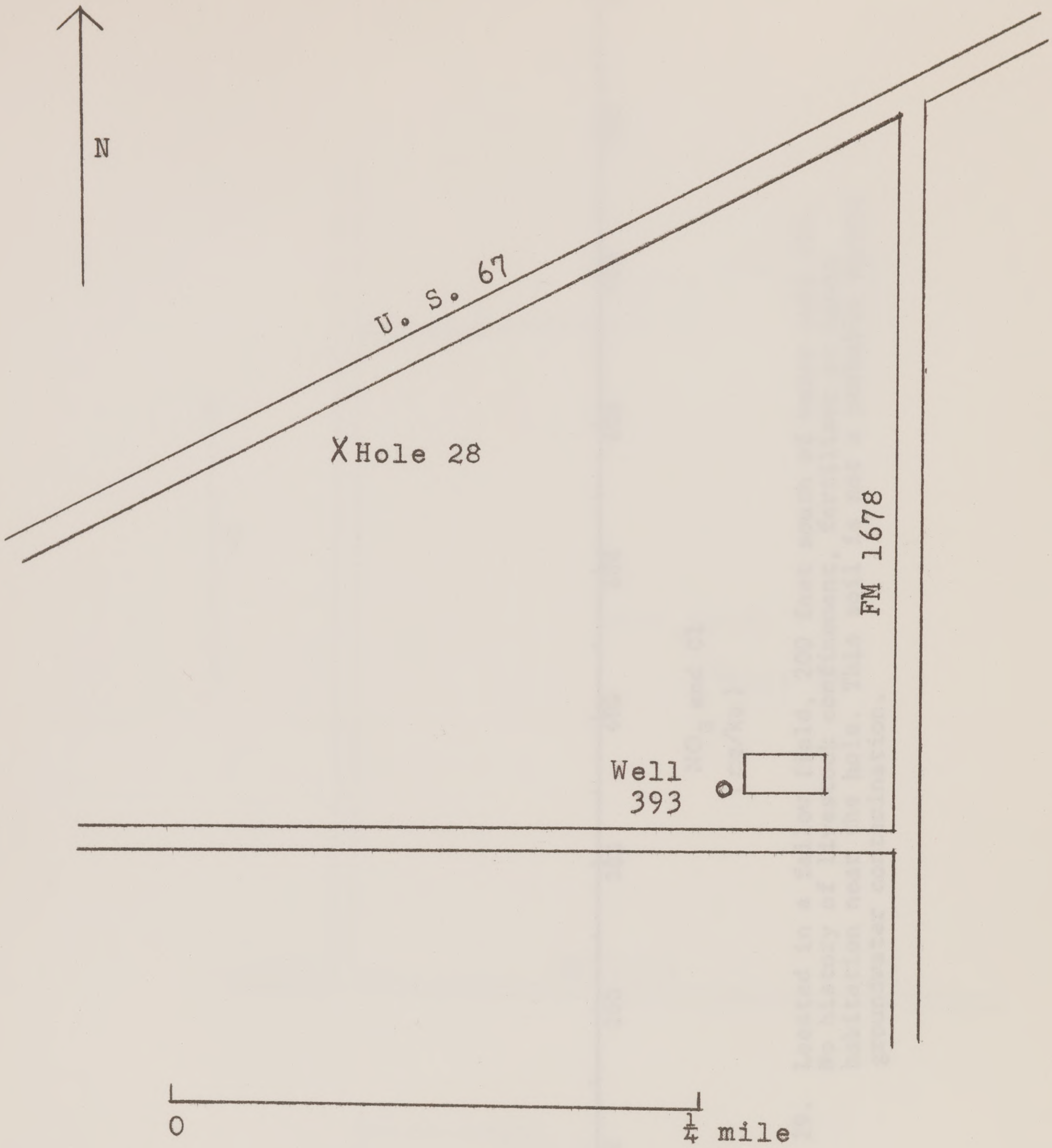
Hole 27. Located in corn field, ¼ mile southwest of water well 867. No history of livestock confinement, fertilizer or human habitation near the hole.



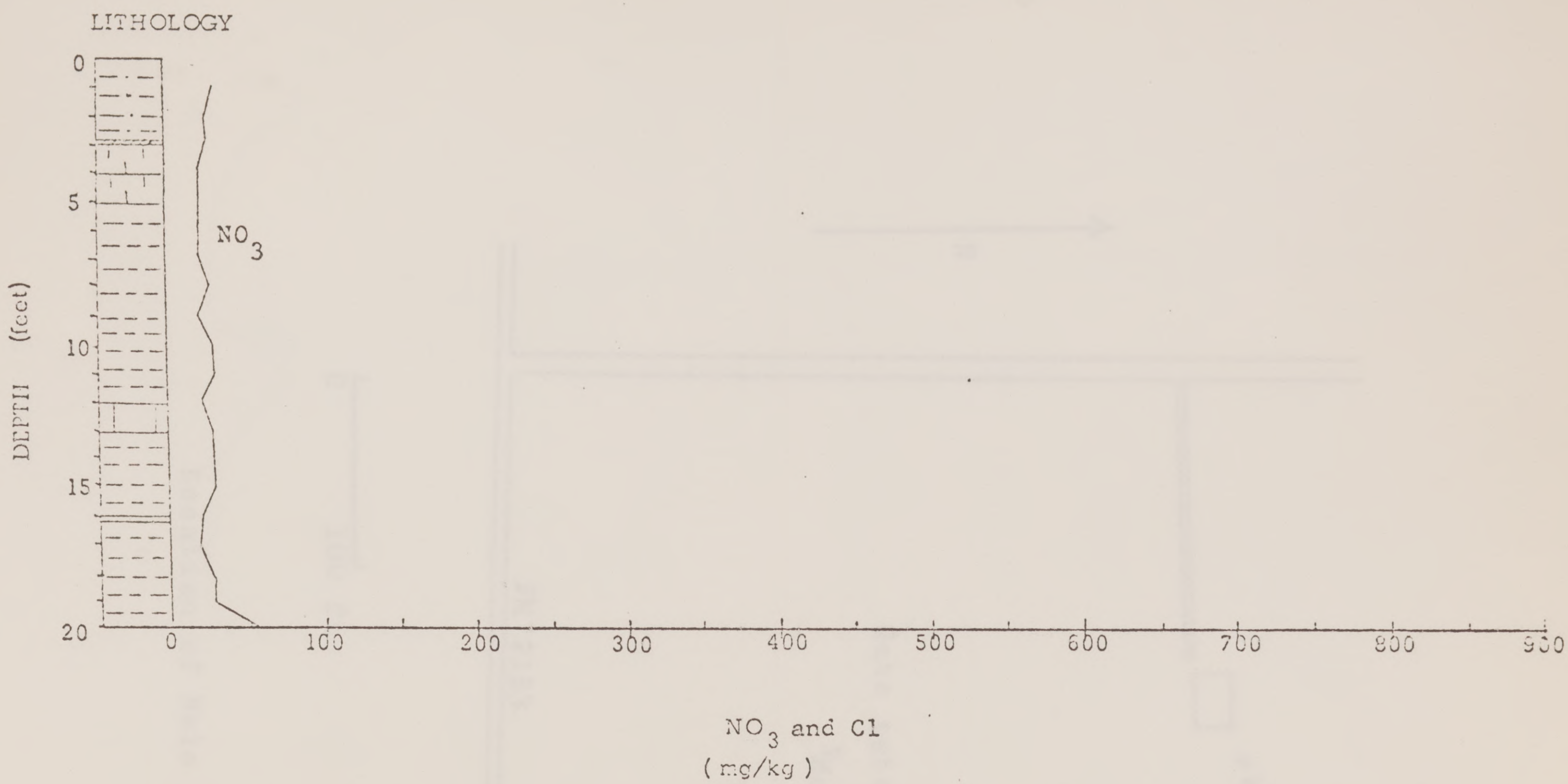
Location of Holes 20, 21, 22, 23, 24, 25, 26, and 27



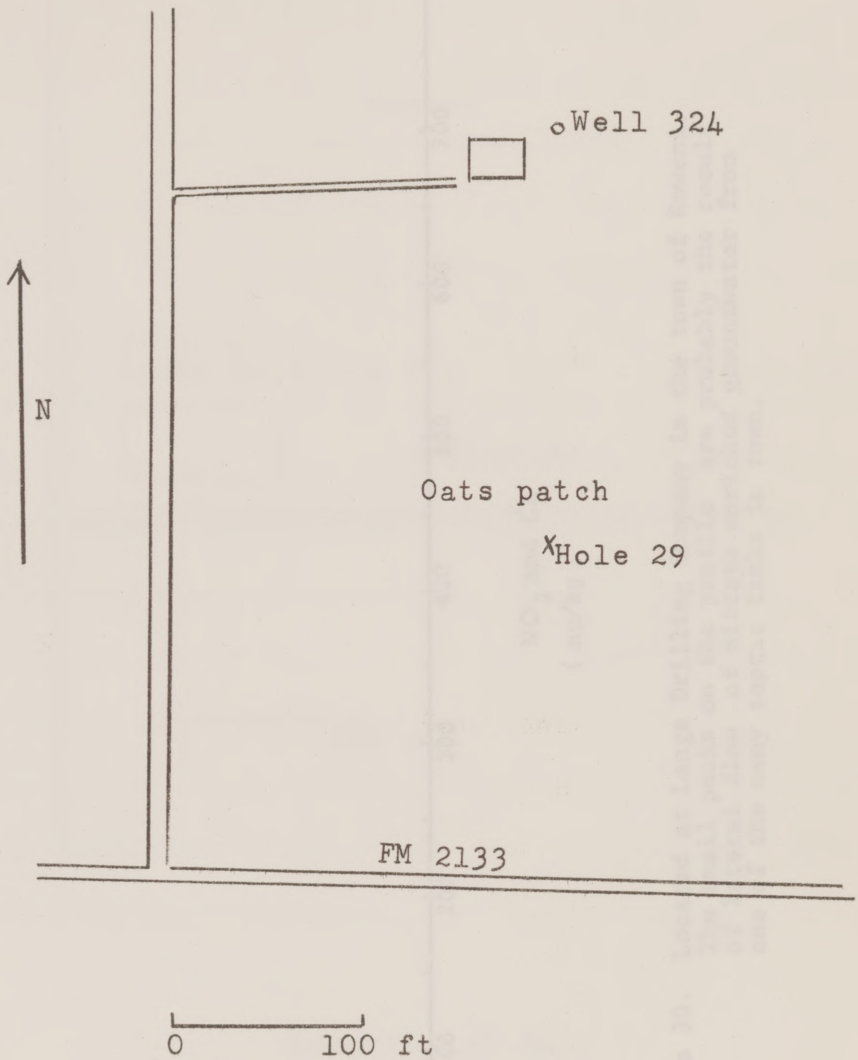
Hole 28. Located in a cotton field, ½ mile northwest of water well 393. No history of livestock confinement, fertilizer or human habitation near the hole. This soil is an unlikely source of groundwater contamination.



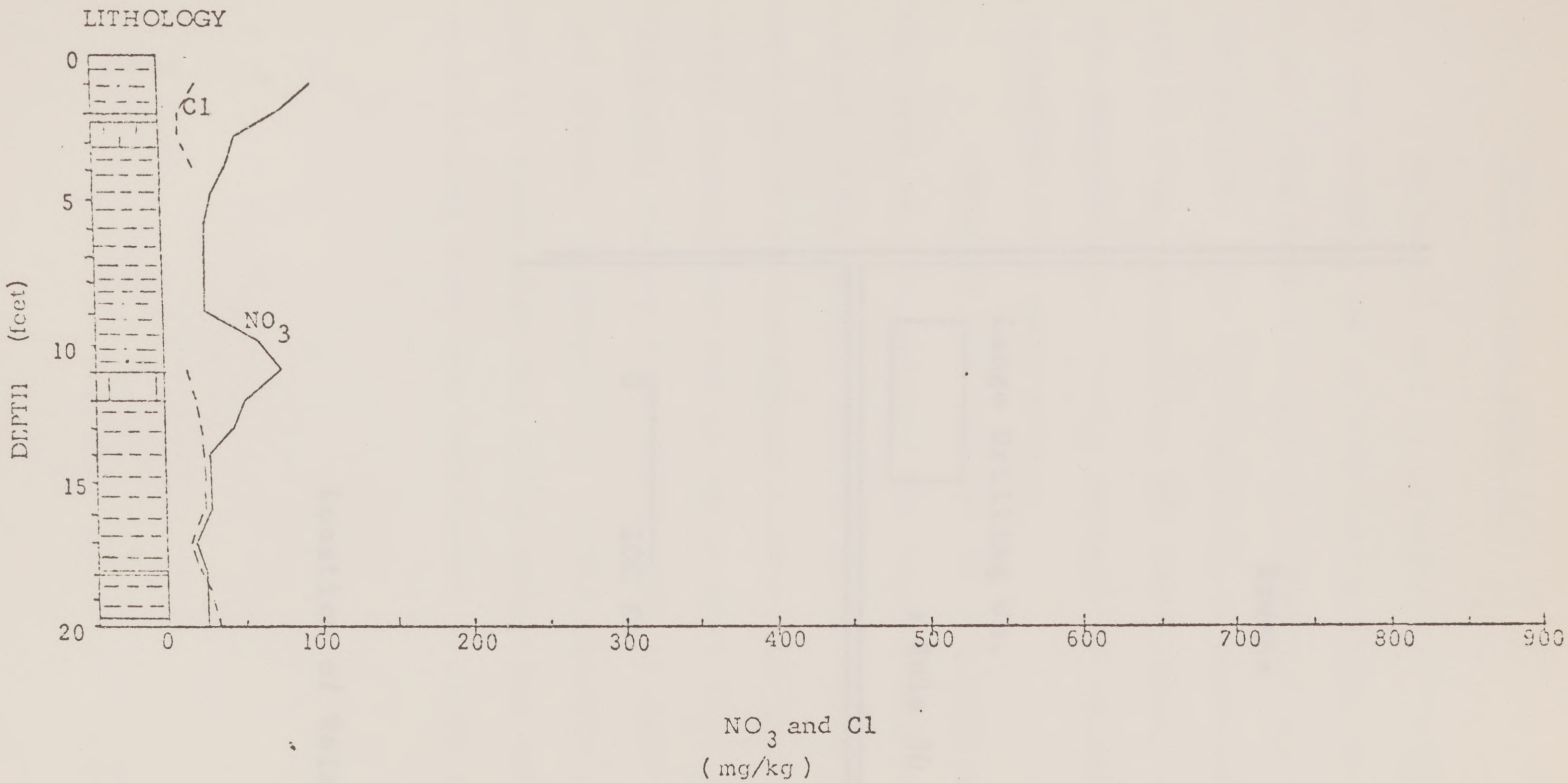
Location of Hole 28



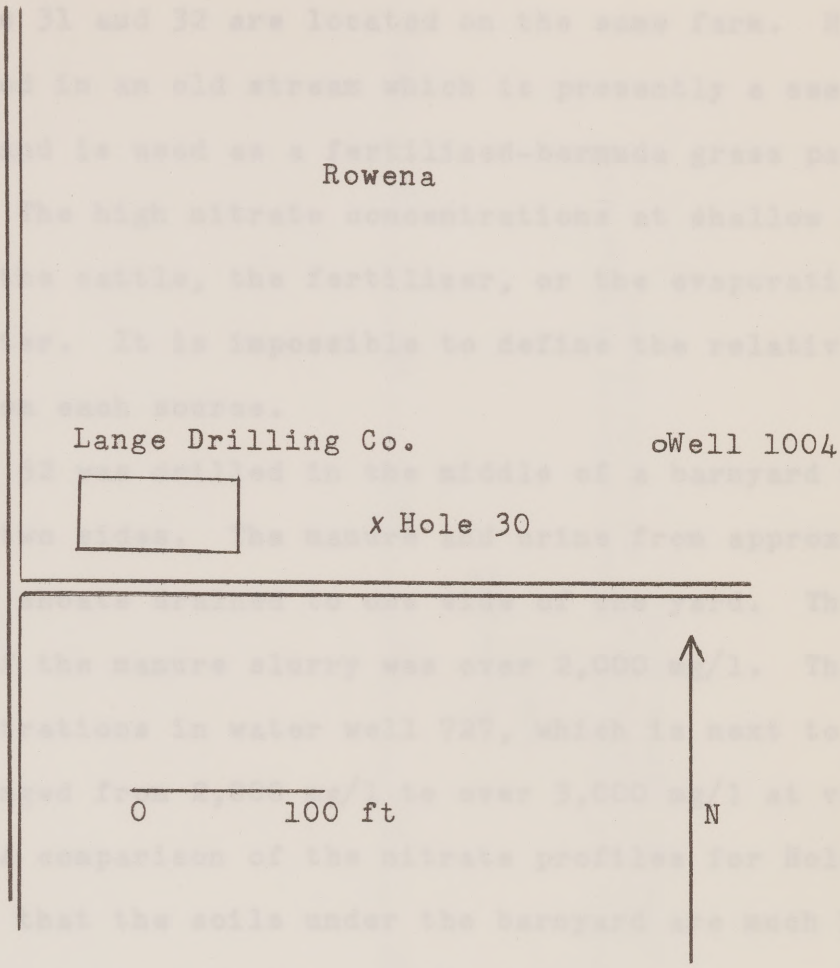
Hole 29. Located in a fallow field, 200 feet south of water well 324. No history of livestock confinement, fertilizer or human habitation near the hole. This soil is not a probable source groundwater contamination.



Location of Hole 29



Hole 30. Located at Lange Drilling Company in the town of Rowena. The small peaks on the profile are probably the result of lateral flow of nitrate enriched groundwater from one of the many septic tanks in town.

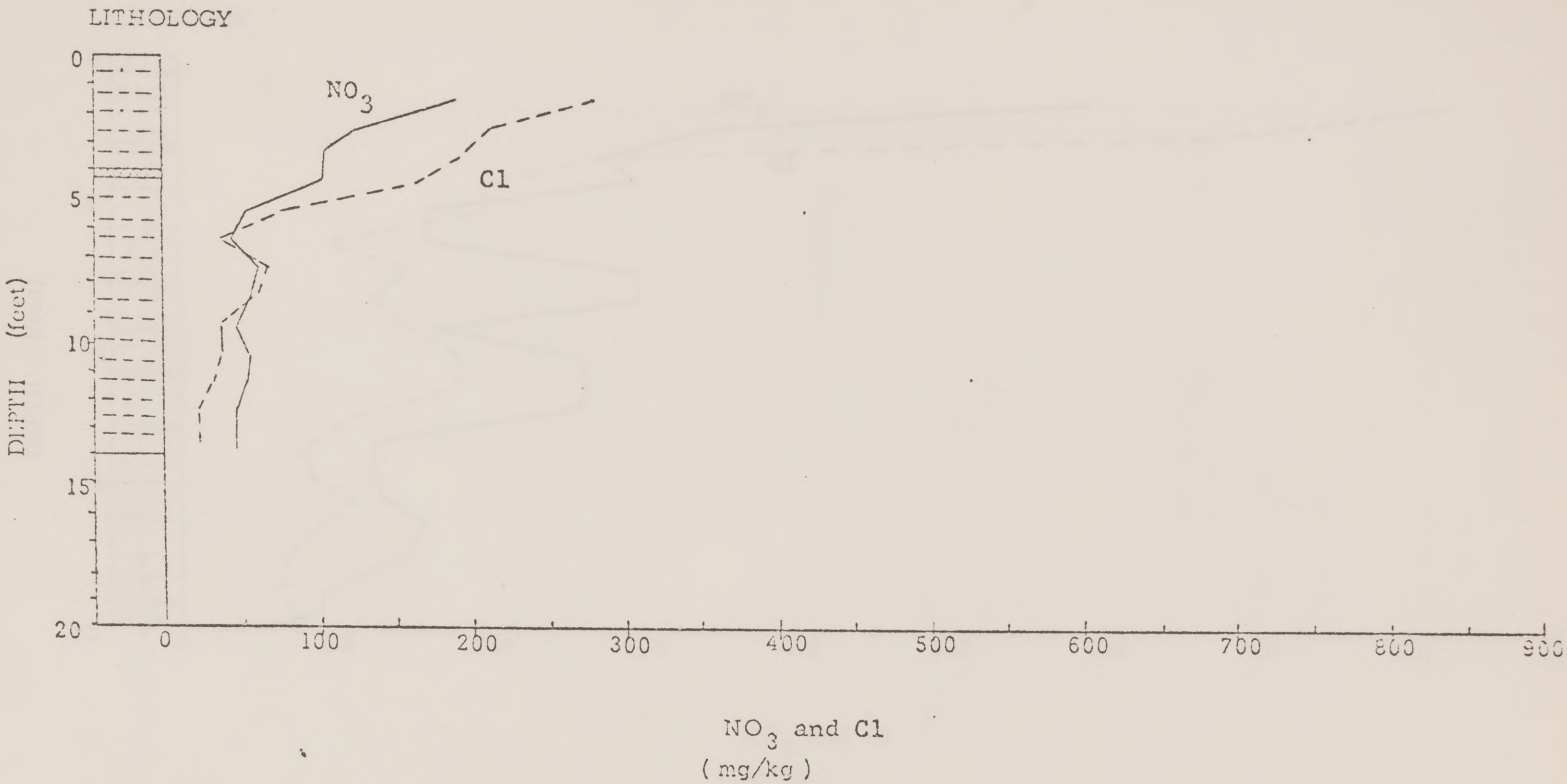


Location of Hole 30

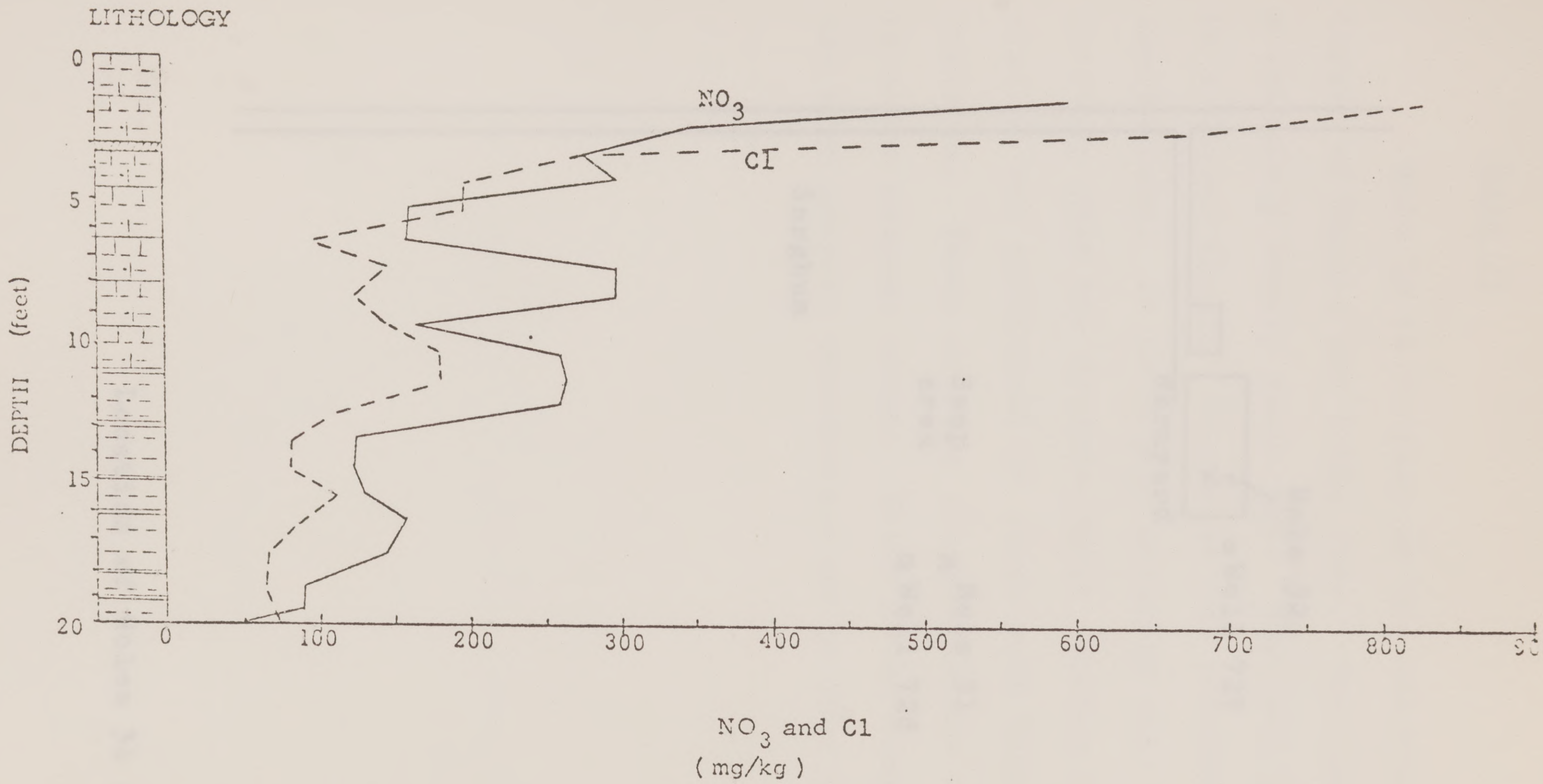
Hole 31 and Hole 32

Holes 31 and 32 are located on the same farm. Hole 31 was drilled in an old stream which is presently a seepage area. The land is used as a fertilized-bermuda grass pasture for cattle. The high nitrate concentrations at shallow depths may be from the cattle, the fertilizer, or the evaporation of the groundwater. It is impossible to define the relative contribution from each source.

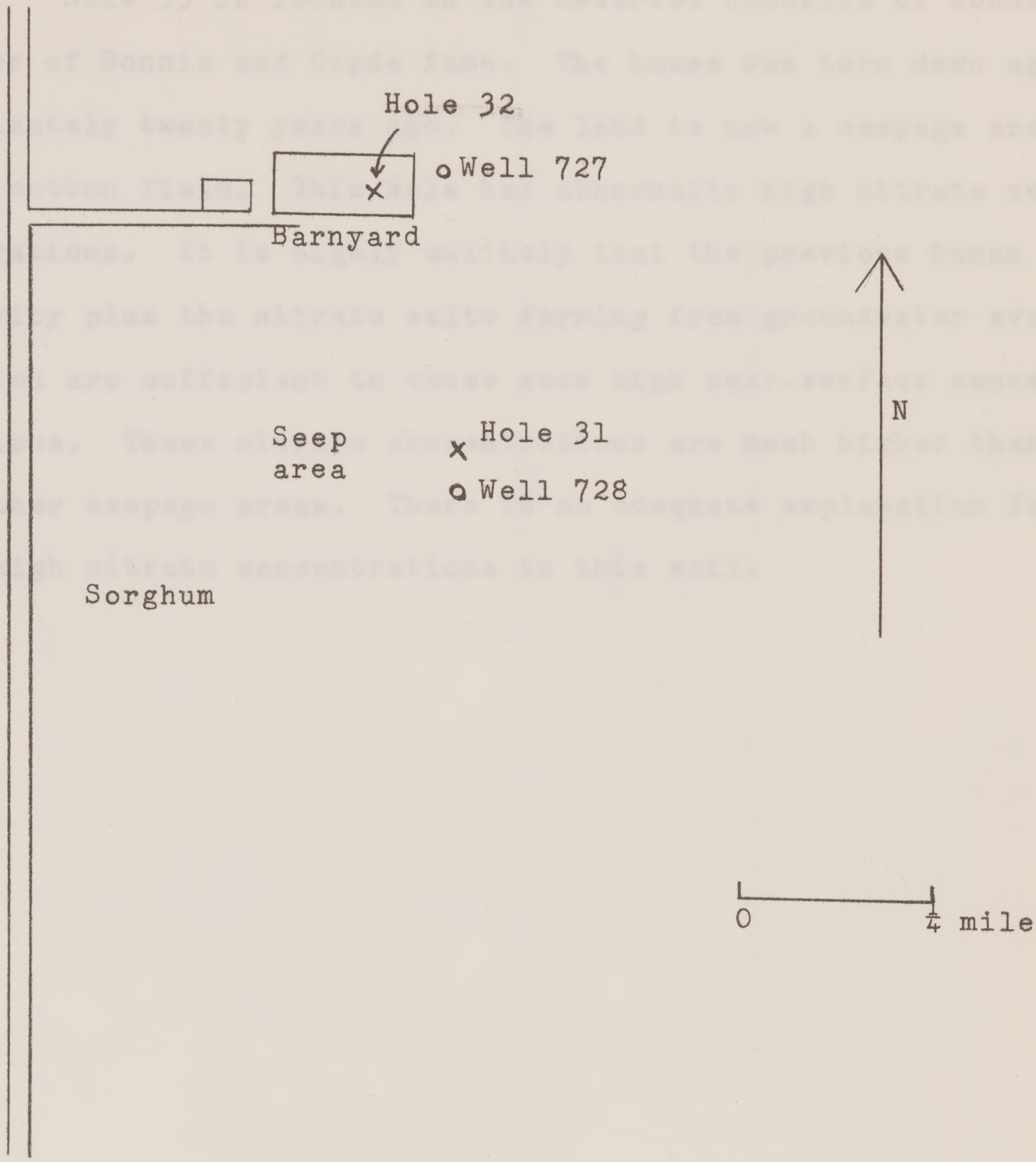
Hole 32 was drilled in the middle of a barnyard with hog pens on two sides. The manure and urine from approximately fifty shoats drained to one side of the yard. The concentration of the manure slurry was over 2,000 mg/l. The nitrate concentrations in water well 727, which is next to the barnyard, ranged from 2,000 mg/l to over 3,000 mg/l at various times. A comparison of the nitrate profiles for Holes 31 and 32 shows that the soils under the barnyard are much higher in nitrates than the fertilized pasture land.



Hole 31. Located in old stream bed, 50 feet northwest of water well 728. Stream bed was seep area and cattle pasture, fertilized for Bermuda grass.



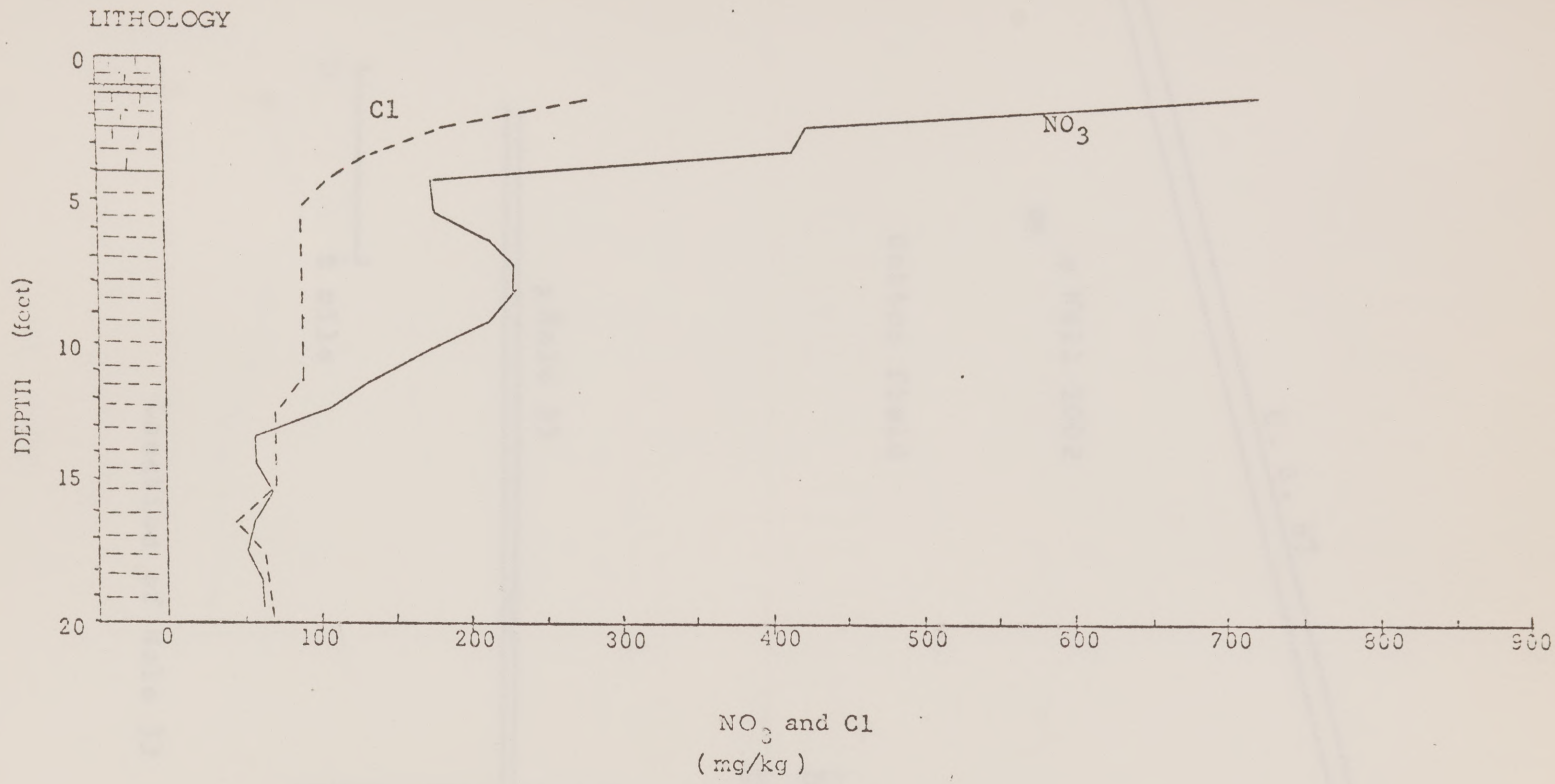
Hole 32. Located in corral, 20 feet south of hog pen and 30 feet west of water well 727.



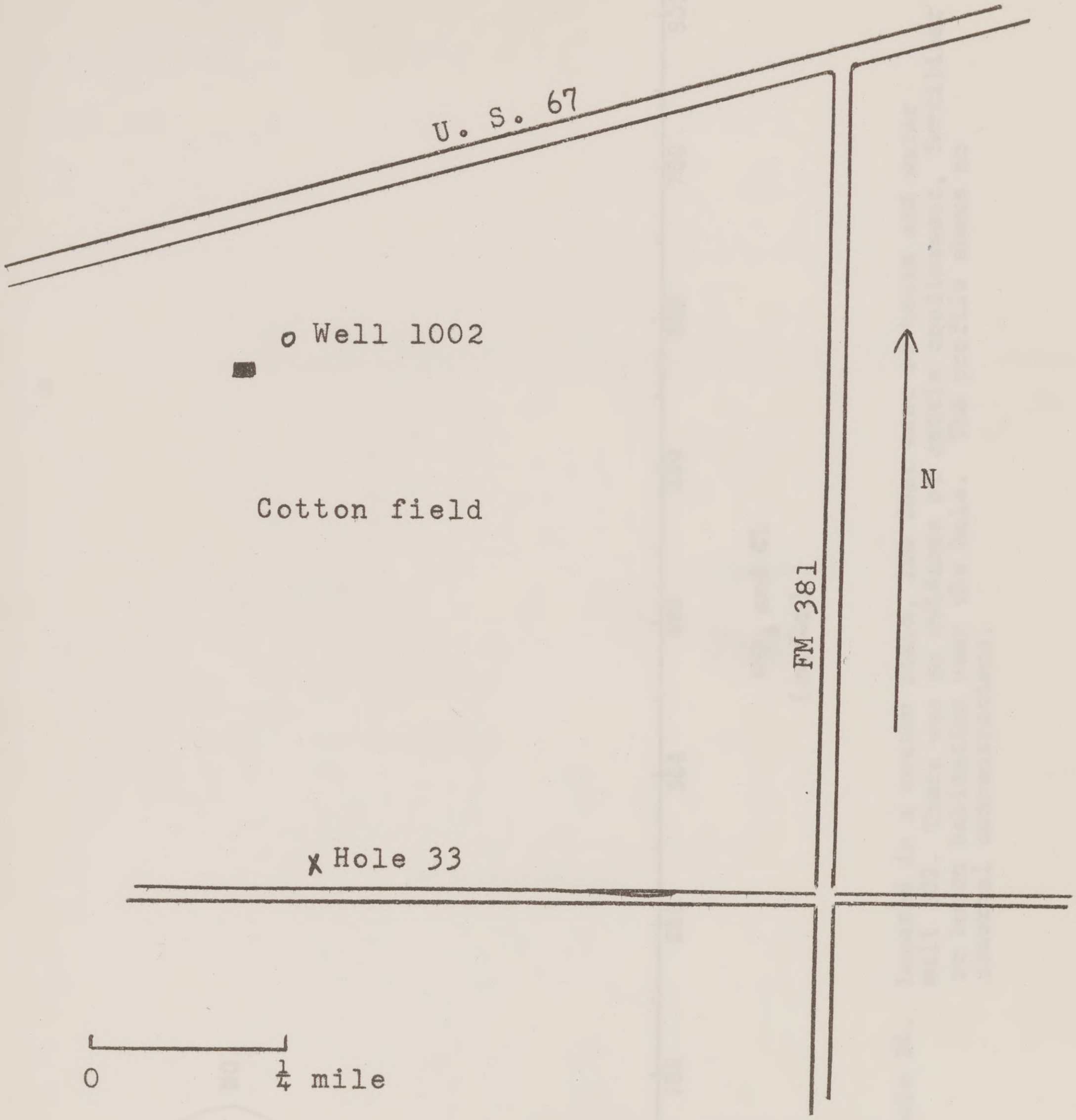
Location of Holes 31 and 32

Hole 33

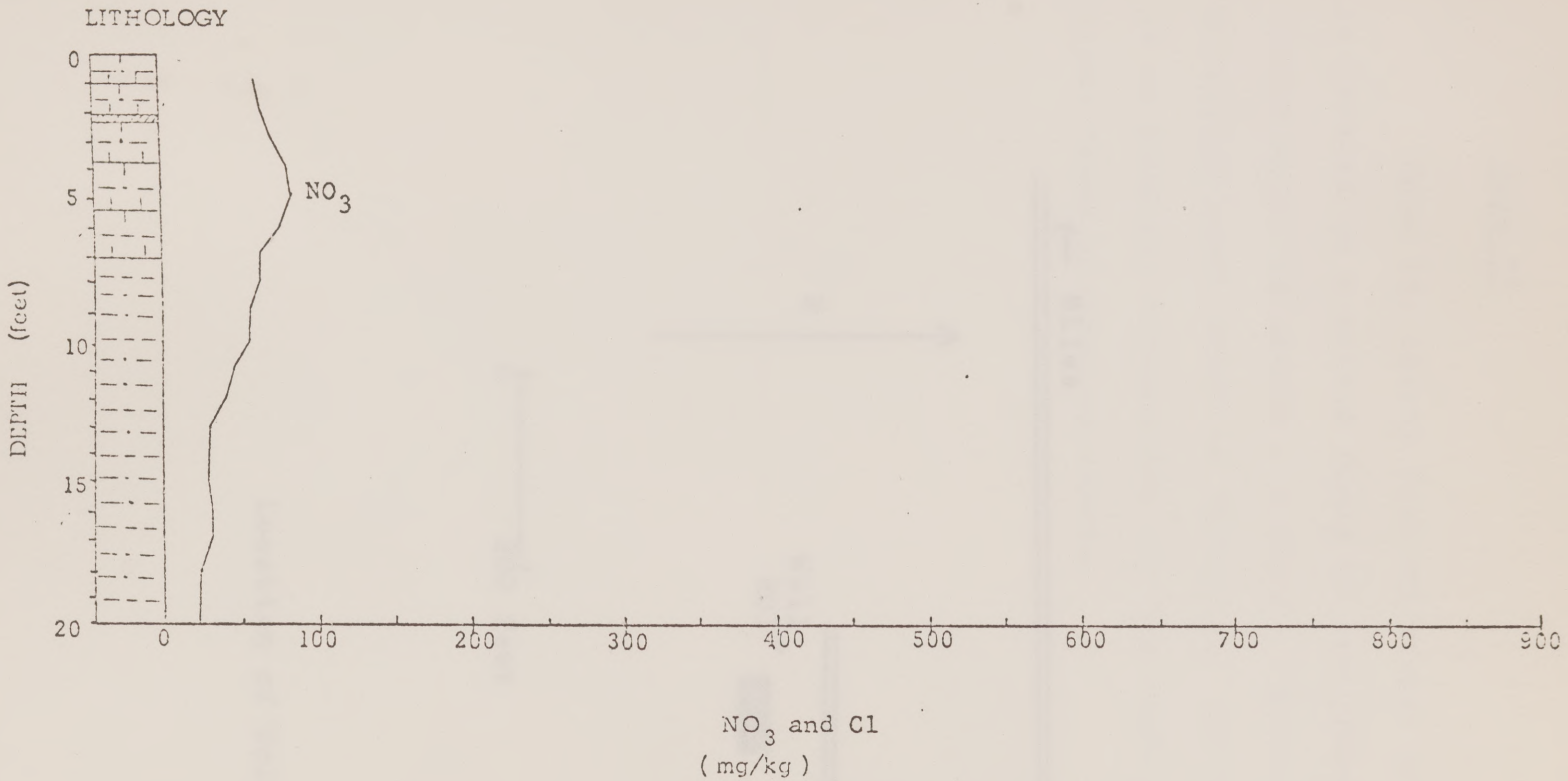
Hole 33 is located on the deserted homesite of Bonnie Parker of Bonnie and Clyde fame. The house was torn down approximately twenty years ago. The land is now a seepage area in a cotton field. This hole has abnormally high nitrate concentrations. It is highly unlikely that the previous human activity plus the nitrate salts forming from groundwater evaporation are sufficient to cause such high near-surface concentrations. These nitrate concentrations are much higher than in other seepage areas. There is no adequate explanation for the high nitrate concentrations in this soil.



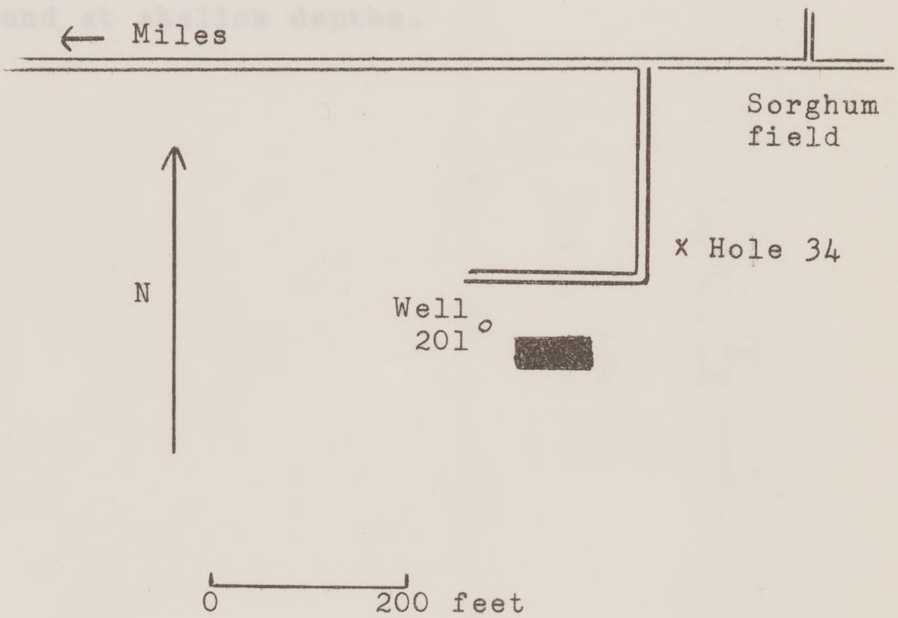
Hole 33. Located on old farm site, ¼ mile south of water well 1002.



Location of Hole 33



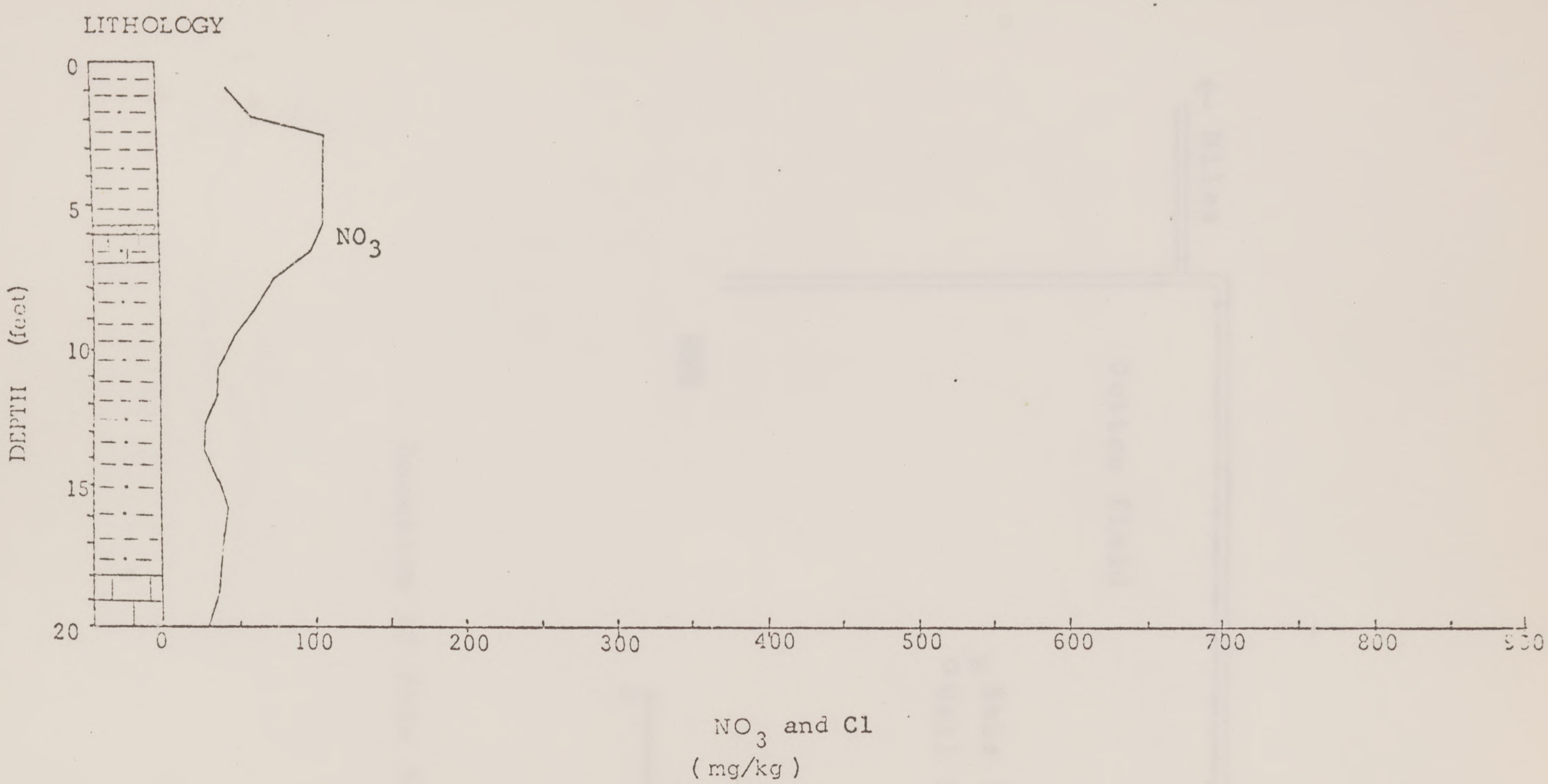
Hole 34. Located in a cotton field, 200 feet east of house and water well 202. There was no evidence of cattle confinement, fertilizer or human habitation near the hole. The profile shows no abnormal concentrations.



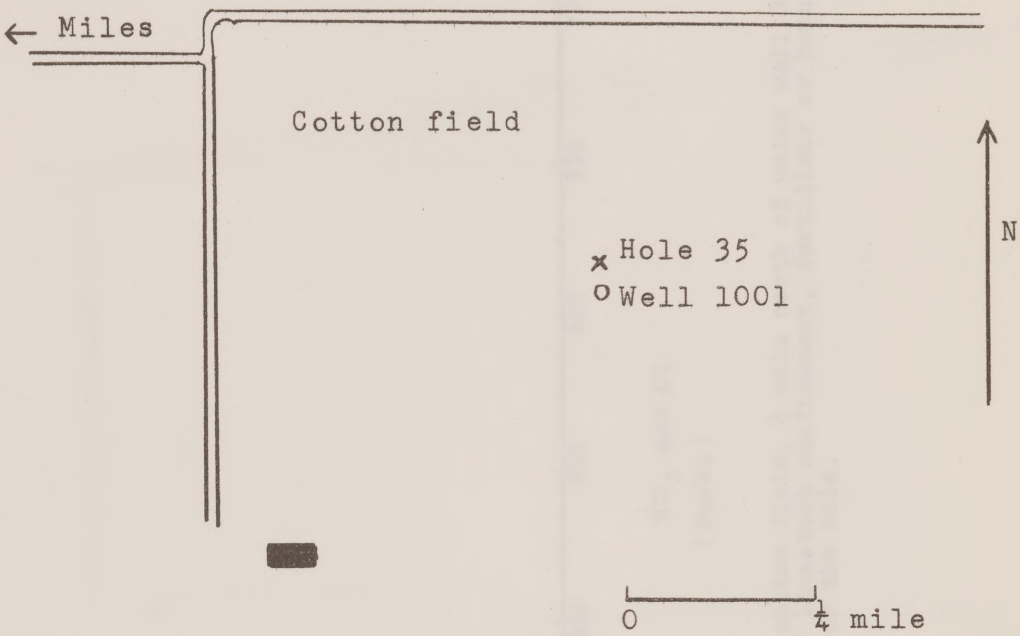
Location of Hole 34

Hole 35

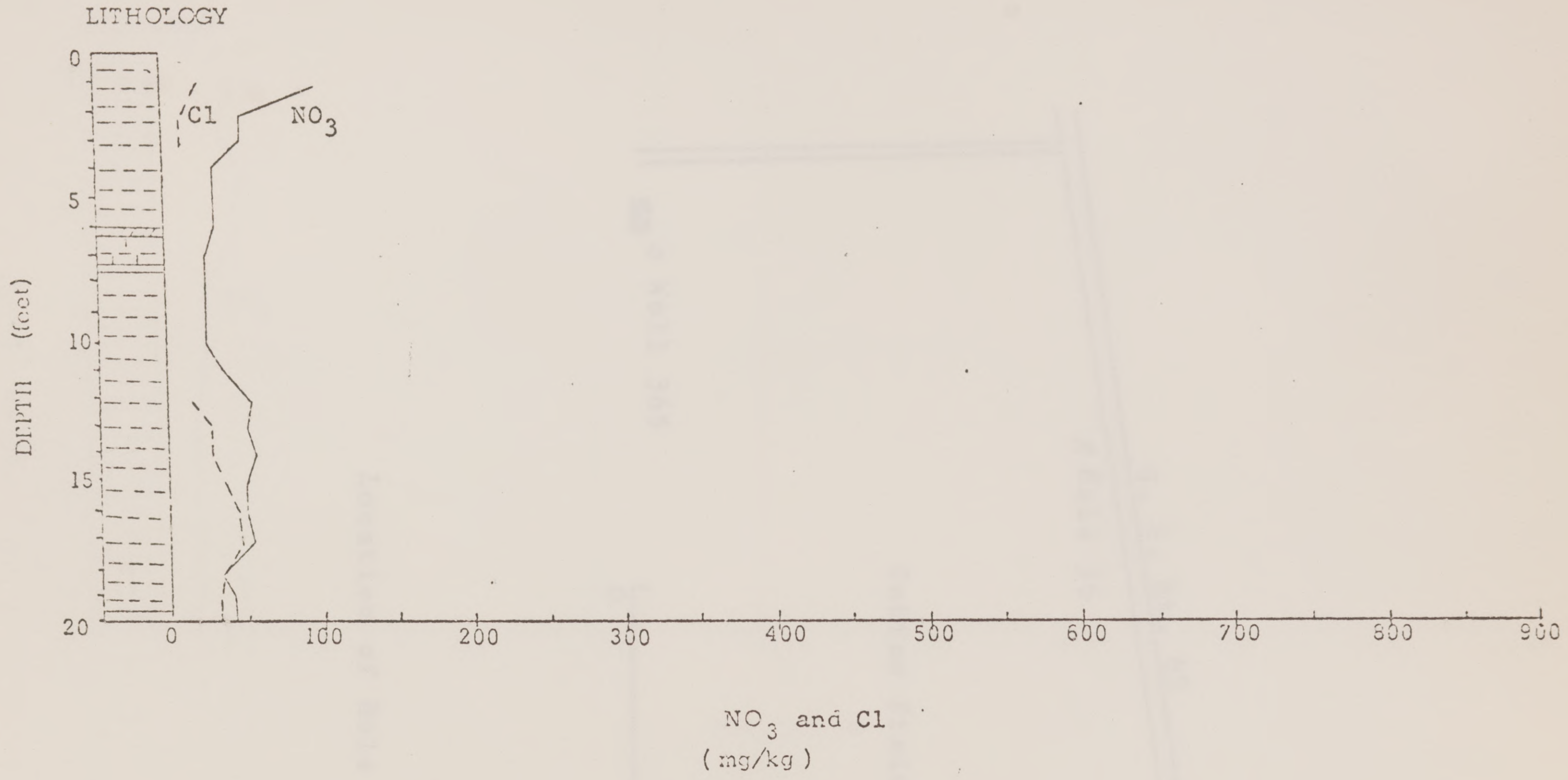
Hole 35, thirty feet northeast of water well 1001, is located in a cotton field in the lowest part of a large, closed basin (diameter - 1 mile). There is no history of livestock confinement or fertilizer use near the hole. There is no adequate explanation for the higher nitrate concentrations found at shallow depths.



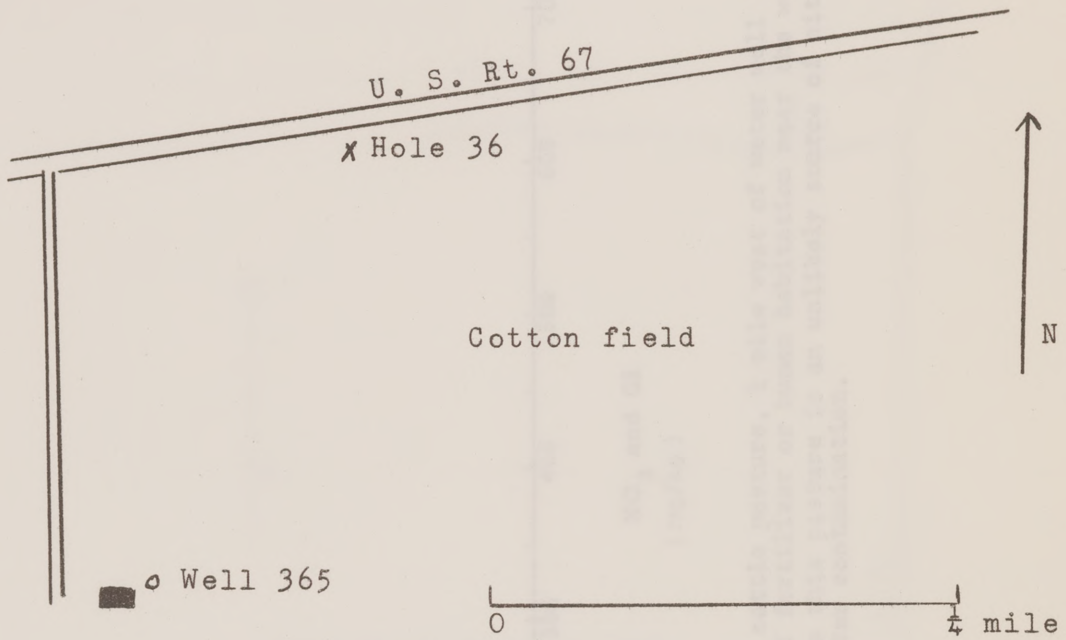
Hole 35. Located in a cotton field in the lowest part of a large, closed, topographic depression (diameter - 1 mile), and 30 feet northeast of water well 1001. No history of livestock confinement or fertilizer usage near the hole.



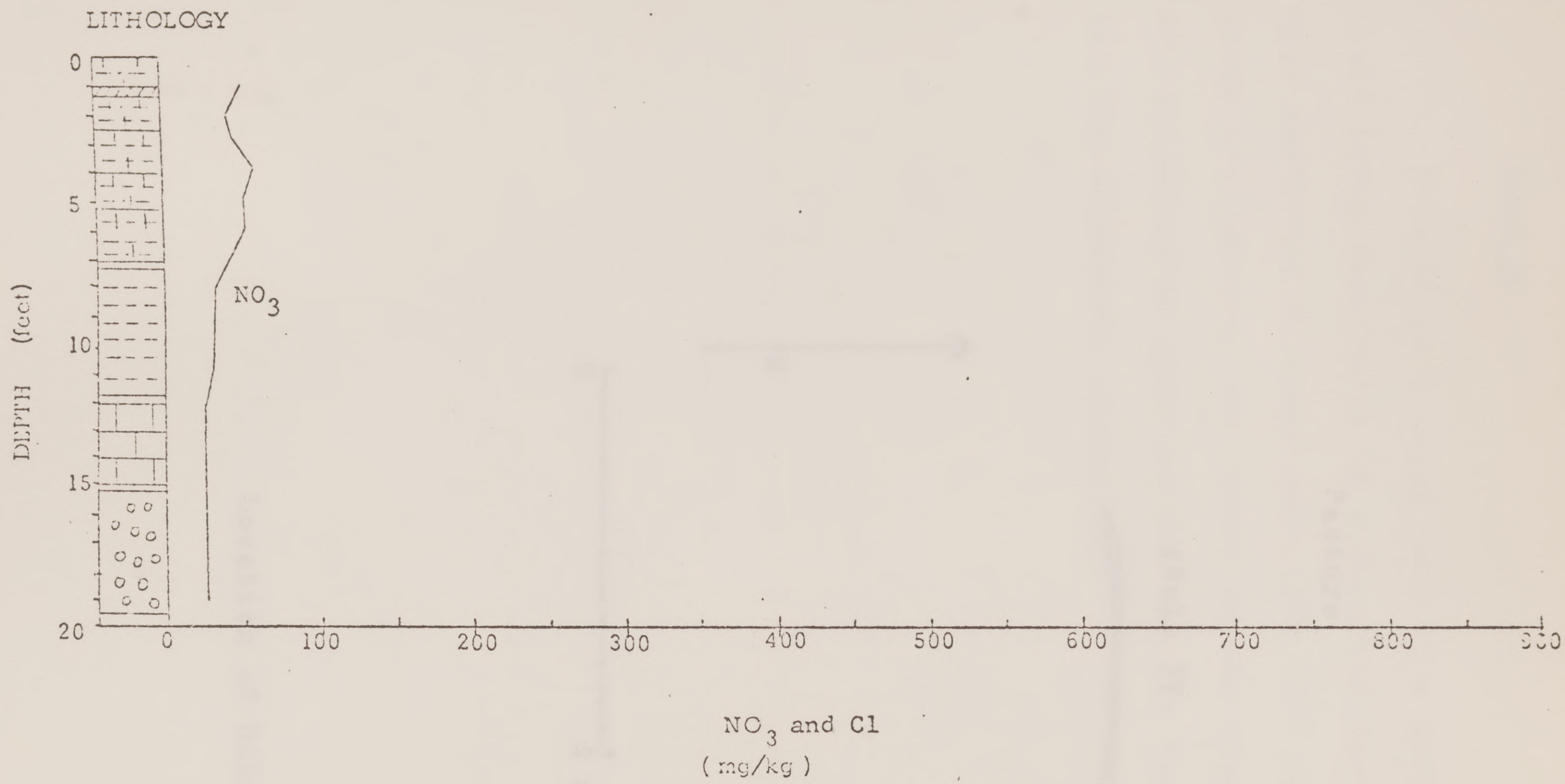
Location of Hole 35



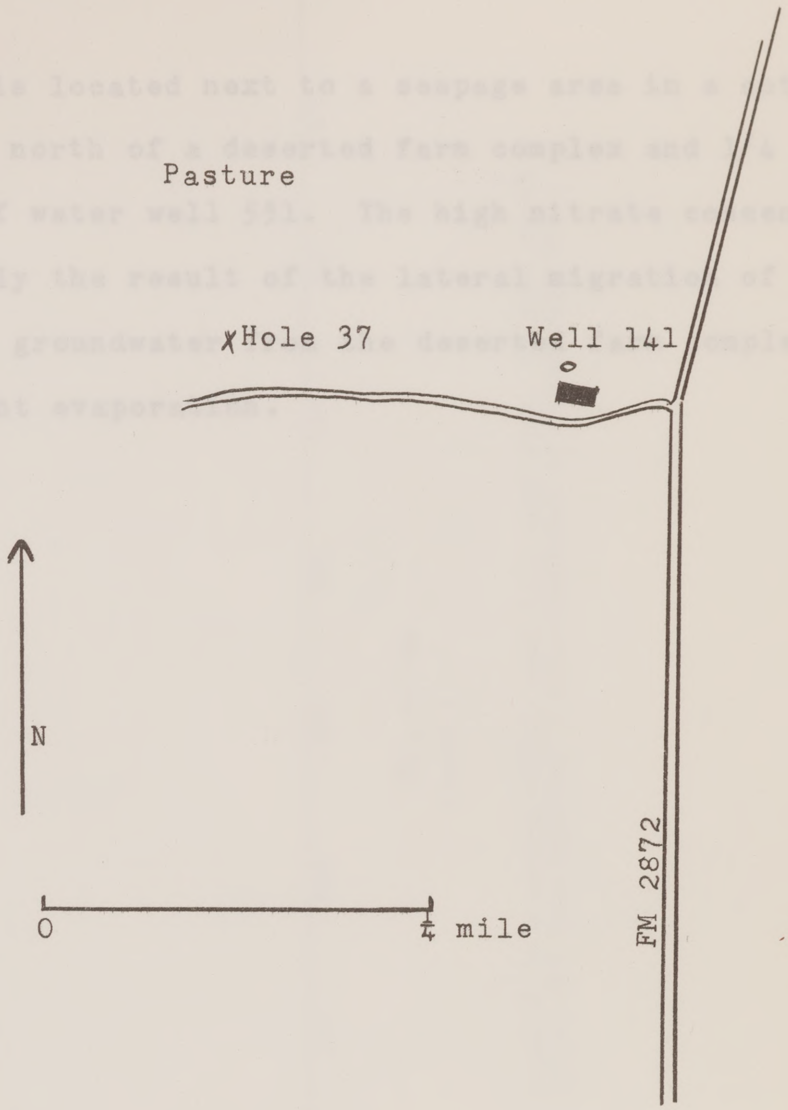
Hole 36. Located in a cotton field, ½ mile north of water well 365. No history of livestock confinement, fertilizer or human habitation near the hole.



Location of Hole 36



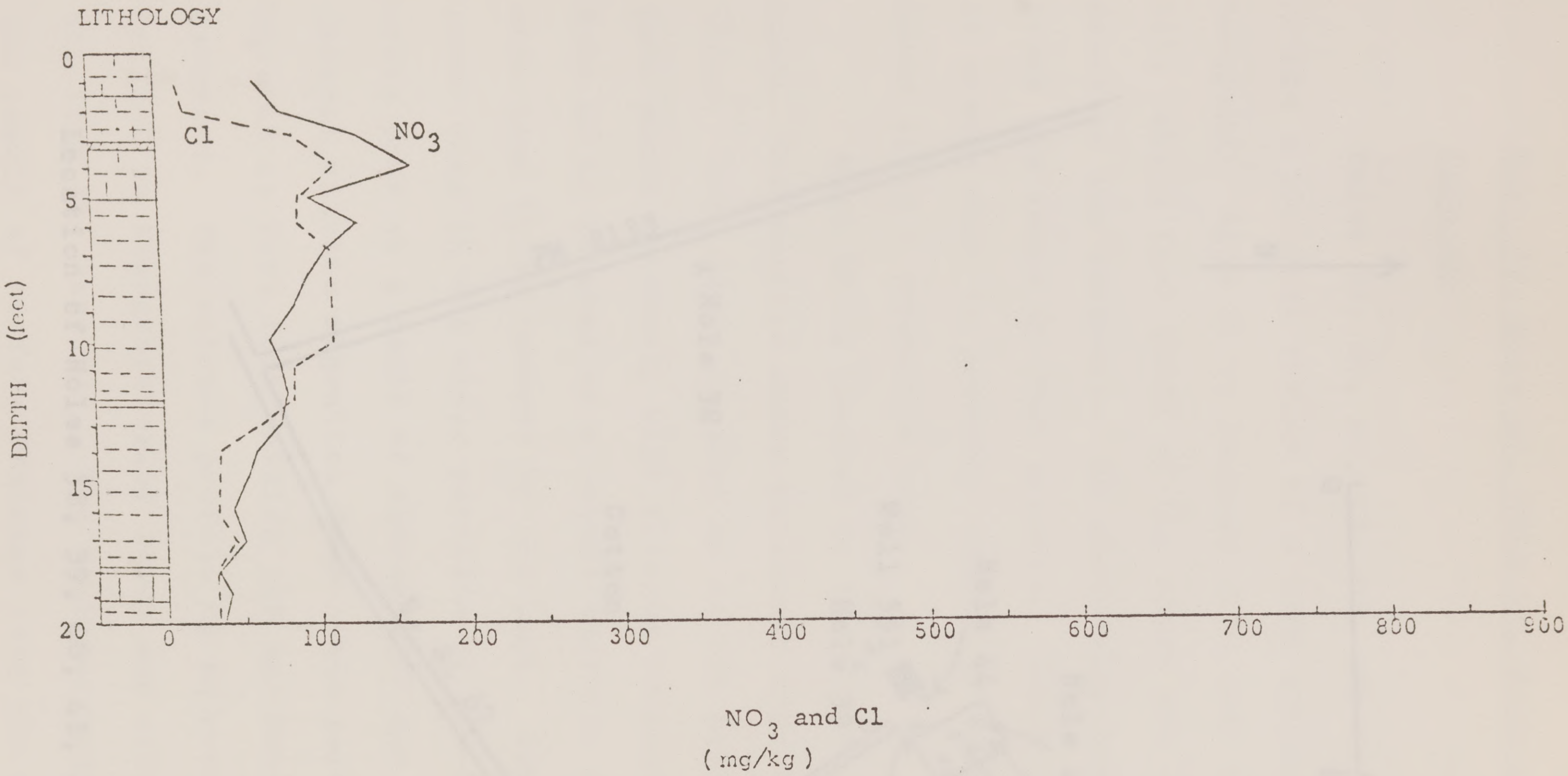
Hole 37. Located in a cattle pasture, ¼ mile west of water well 141. No history of fertilizer or human habitation near the well. The soil from this pasture is an unlikely source of nitrate for groundwater contamination.



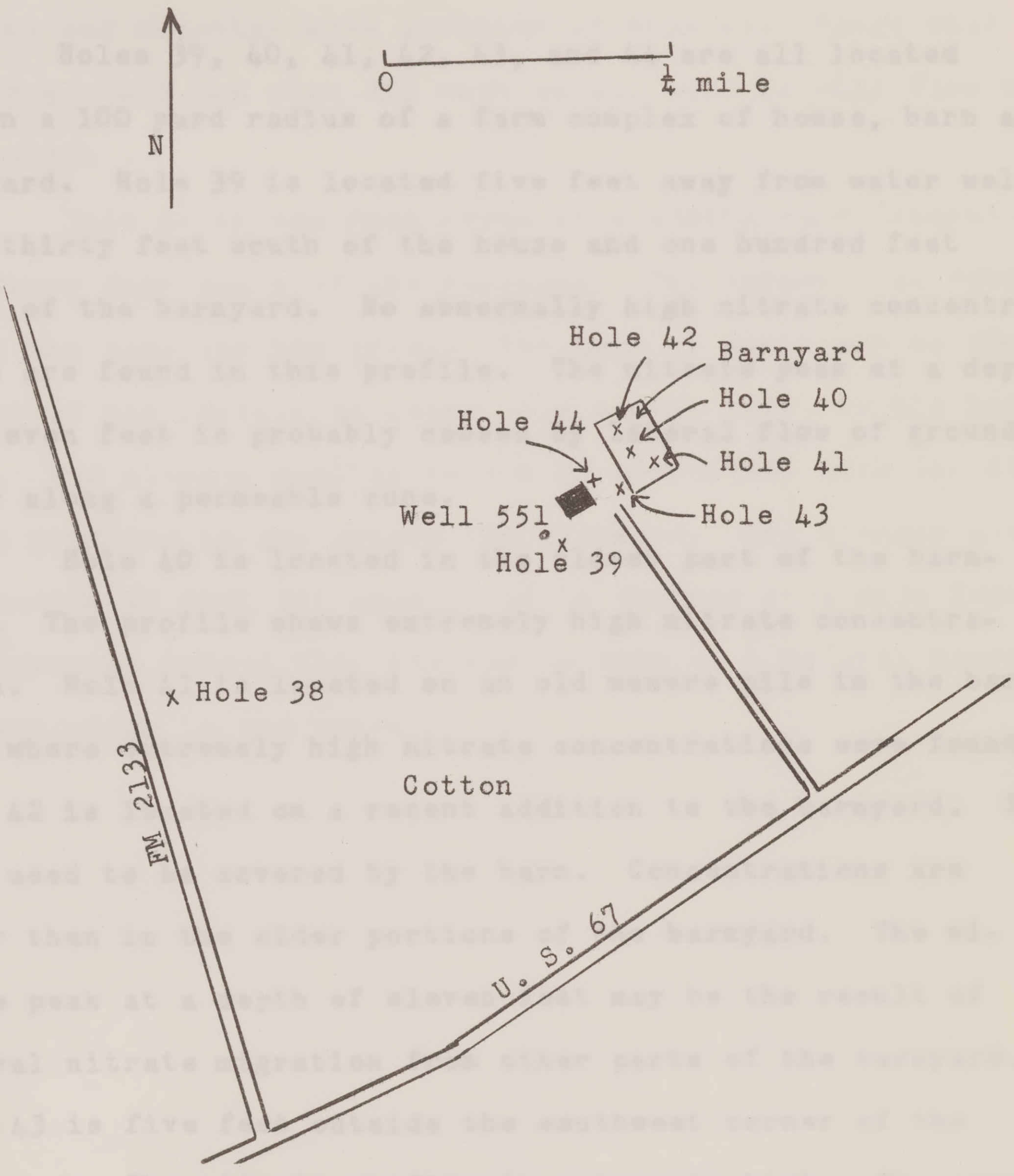
Location of Hole 37

Hole 38

Hole 38 is located next to a seepage area in a cotton field fifty feet north of a deserted farm complex and 1/4 mile southwest of water well 551. The high nitrate concentrations are probably the result of the lateral migration of nitrate-enriched groundwater from the deserted farm complex and its subsequent evaporation.



Hole 38. Located in a cotton field, next to a seep area, 50 feet north of an old farm site and ¼ mile southwest of water well 551.



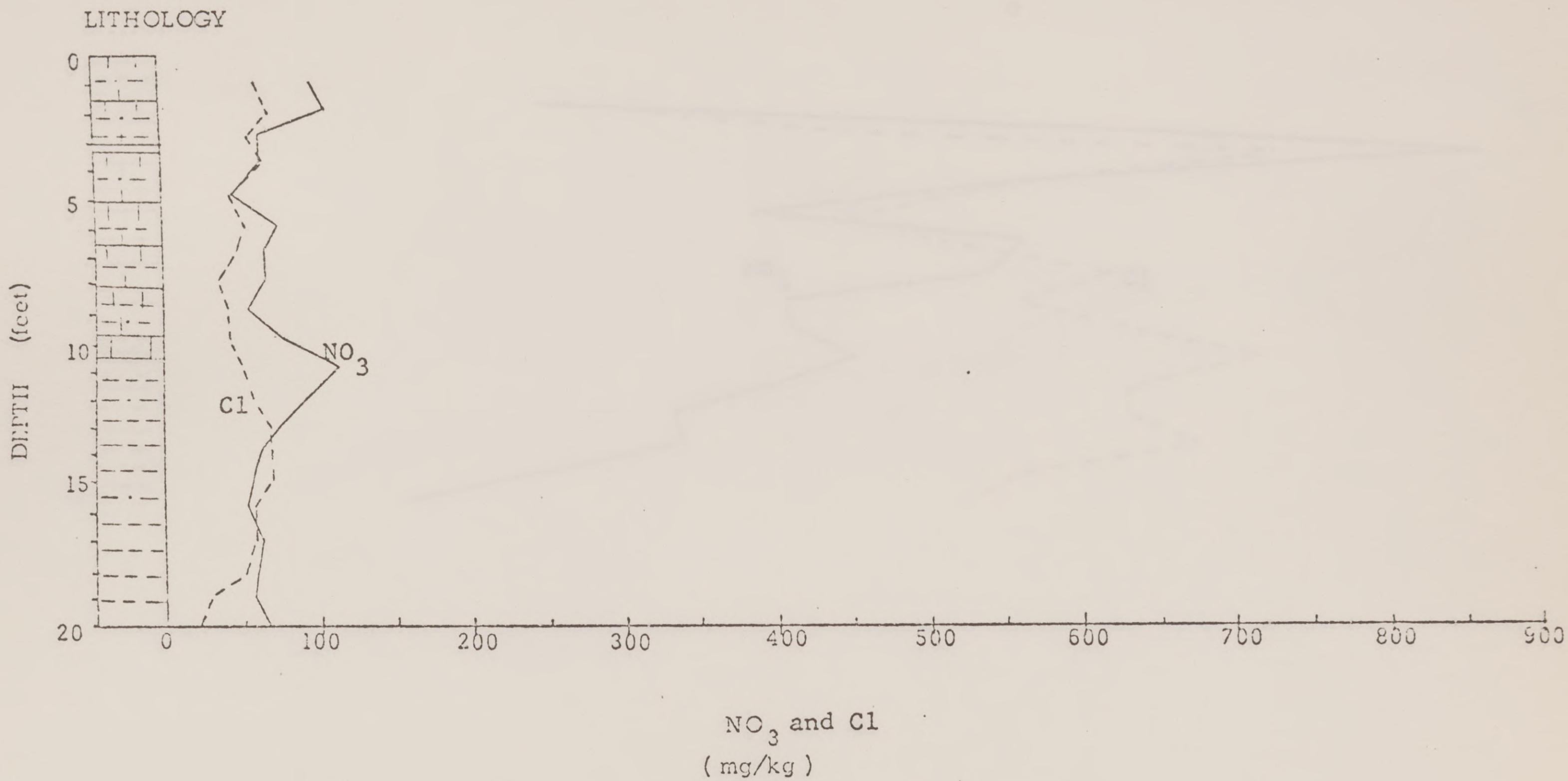
Location of Holes 38, 39, 40, 41, 42, 43, and 44

Hole 39, Hole 40, Hole 41, Hole 42, Hole 43, and Hole 44

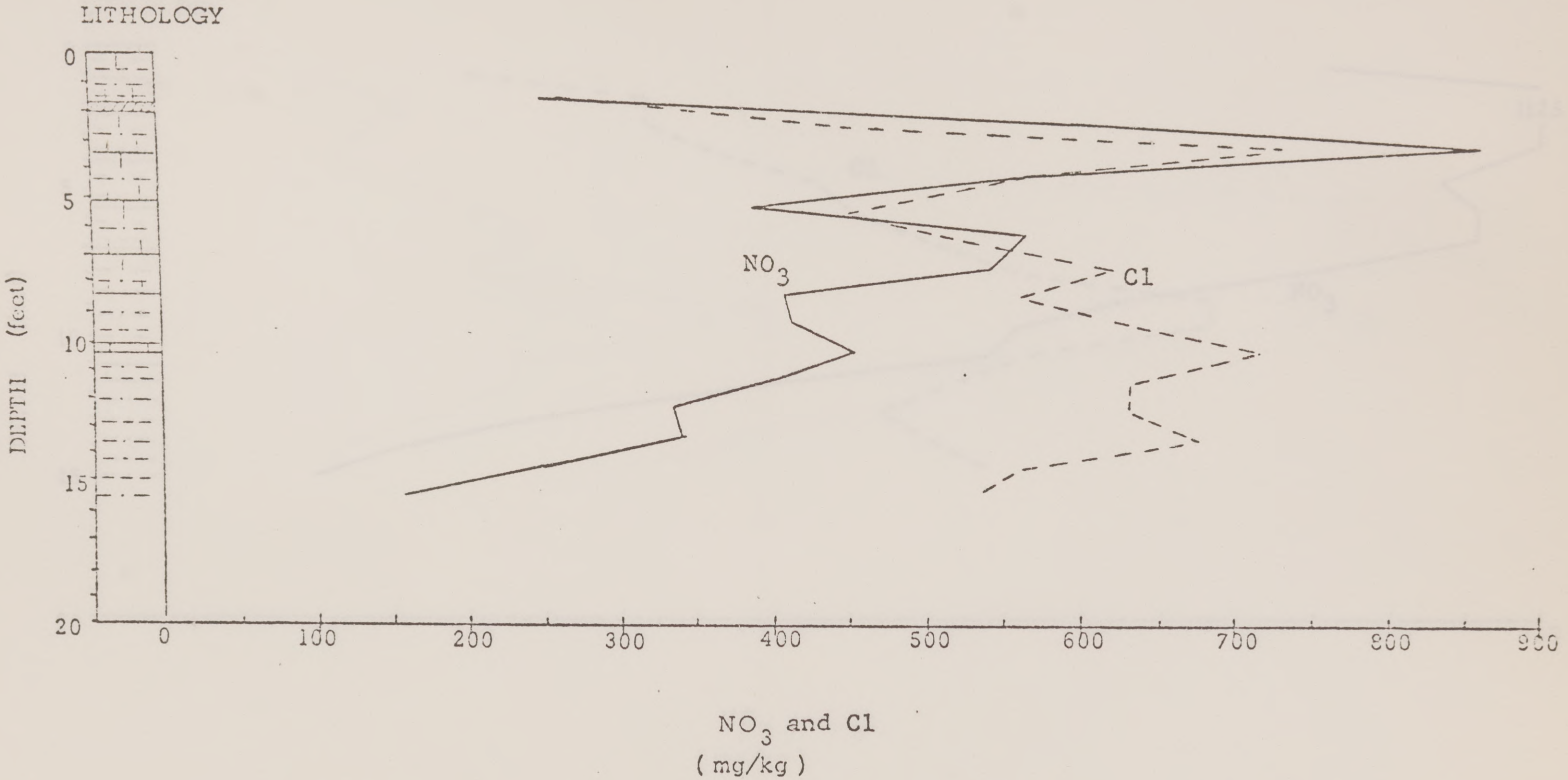
Holes 39, 40, 41, 42, 43, and 44 are all located within a 100 yard radius of a farm complex of house, barn and barnyard. Hole 39 is located five feet away from water well 551, thirty feet south of the house and one hundred feet south of the barnyard. No abnormally high nitrate concentrations are found in this profile. The nitrate peak at a depth of eleven feet is probably caused by lateral flow of groundwater along a permeable zone.

Hole 40 is located in the oldest part of the barnyard. The profile shows extremely high nitrate concentrations. Hole 41 is located on an old manure pile in the barnyard where extremely high nitrate concentrations were found. Hole 42 is located on a recent addition to the barnyard. The area used to be covered by the barn. Concentrations are lower than in the older portions of the barnyard. The nitrate peak at a depth of eleven feet may be the result of lateral nitrate migration from other parts of the barnyard. Hole 43 is five feet outside the southwest corner of the barnyard. The nitrate profile is extremely high. The area drilled is topographically lower and stratigraphically down dip from the barnyard. The high concentrations are probably the result of surface drainage from the barnyard and subsurface lateral migration of nitrates. The concentrations in Hole 43 are higher than in Hole 42 because of the topographic and stratigraphic position of Hole 43. Water will flow downslope and down dip much easier than it will flow horizontally.

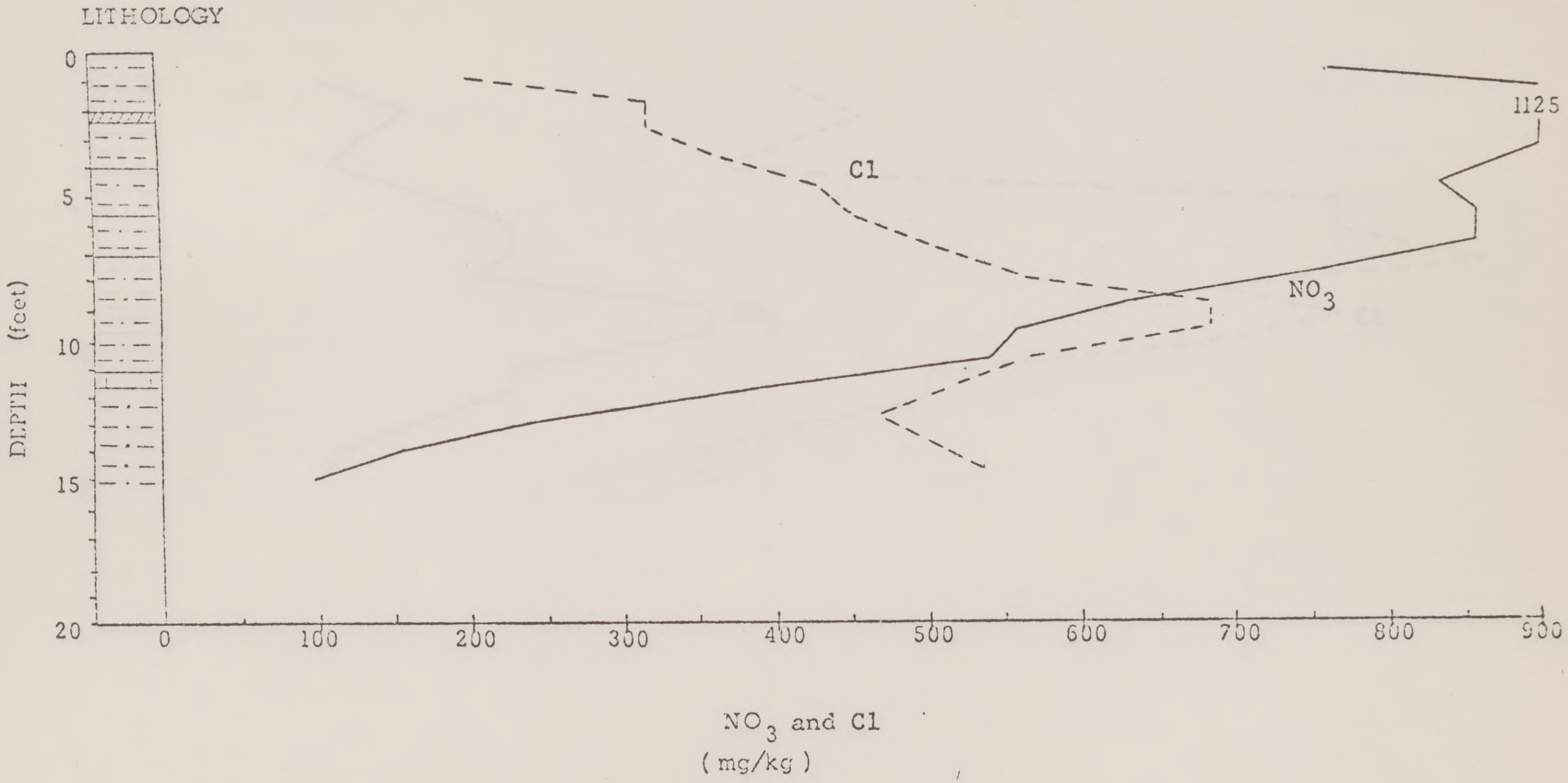
Hole 44 is ten feet north of a septic tank lateral and forty feet south of the barnyard. The farmer also fertilized the area for his grass. The peak at depth may be the result of his fertilizer usage, his septic tank, or his barnyard. The nitrate profile is low in comparison with the nitrate profiles in and around the barnyard. The nitrate contamination of well 551 appears to be derived primarily from the barnyard rather than the septic tank or a natural nitrate concentration in the soils.



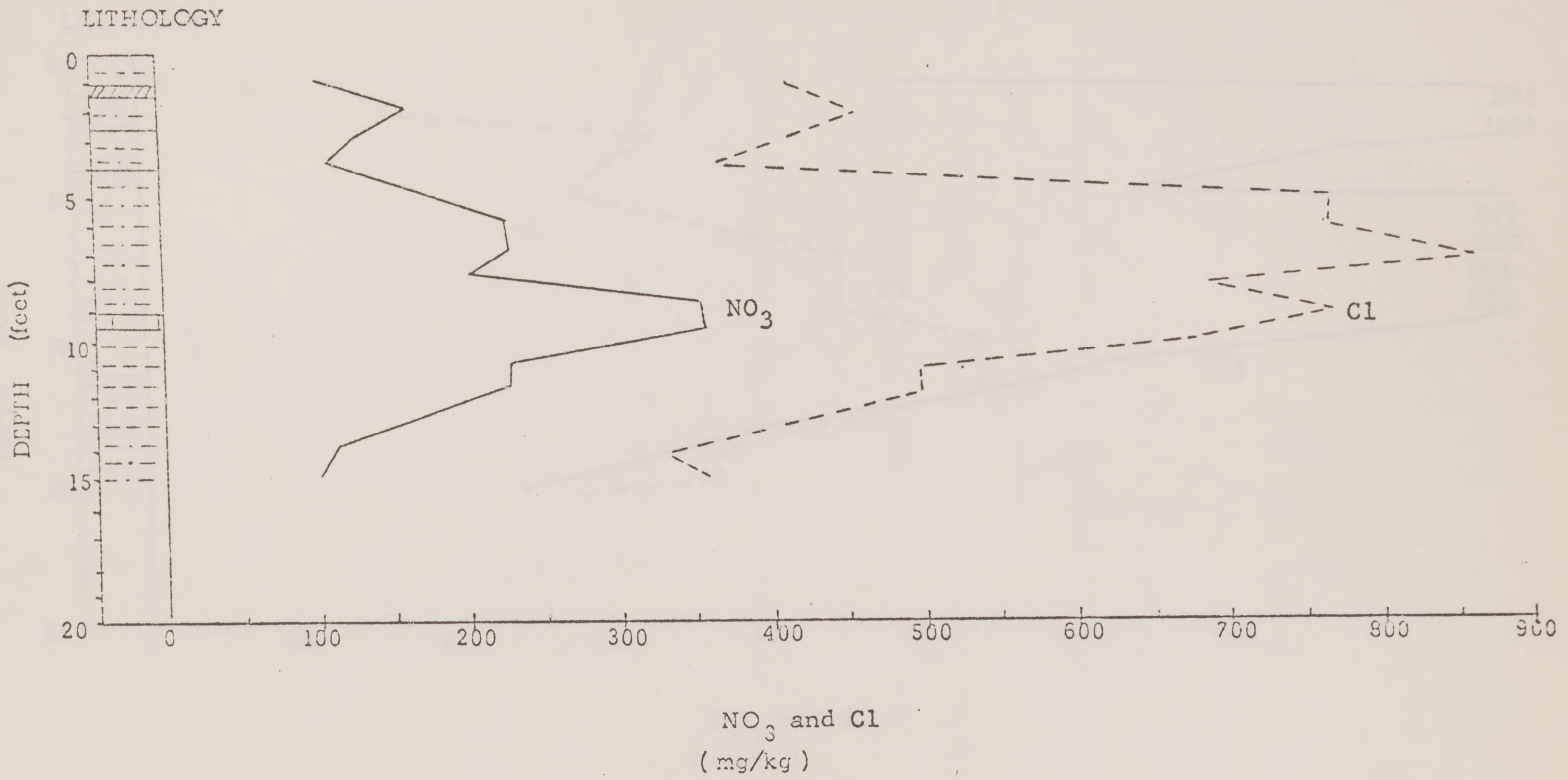
Hole 39. Located 30 feet south of a house, 100 feet south of the barnyard and 5 feet north of water well 551.



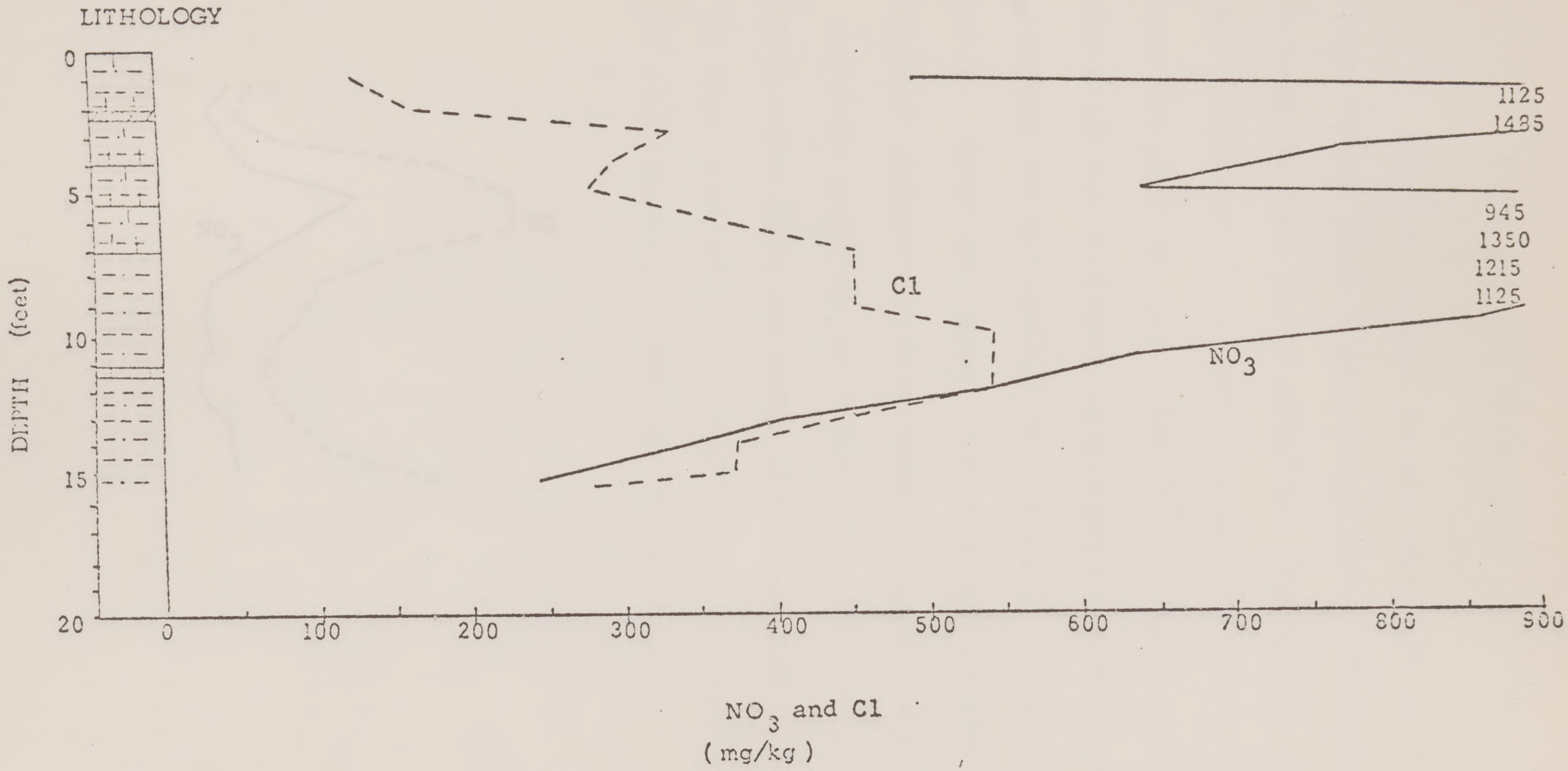
Hole 40. Located in the oldest part of a barnyard and 100 feet north of water well 551.



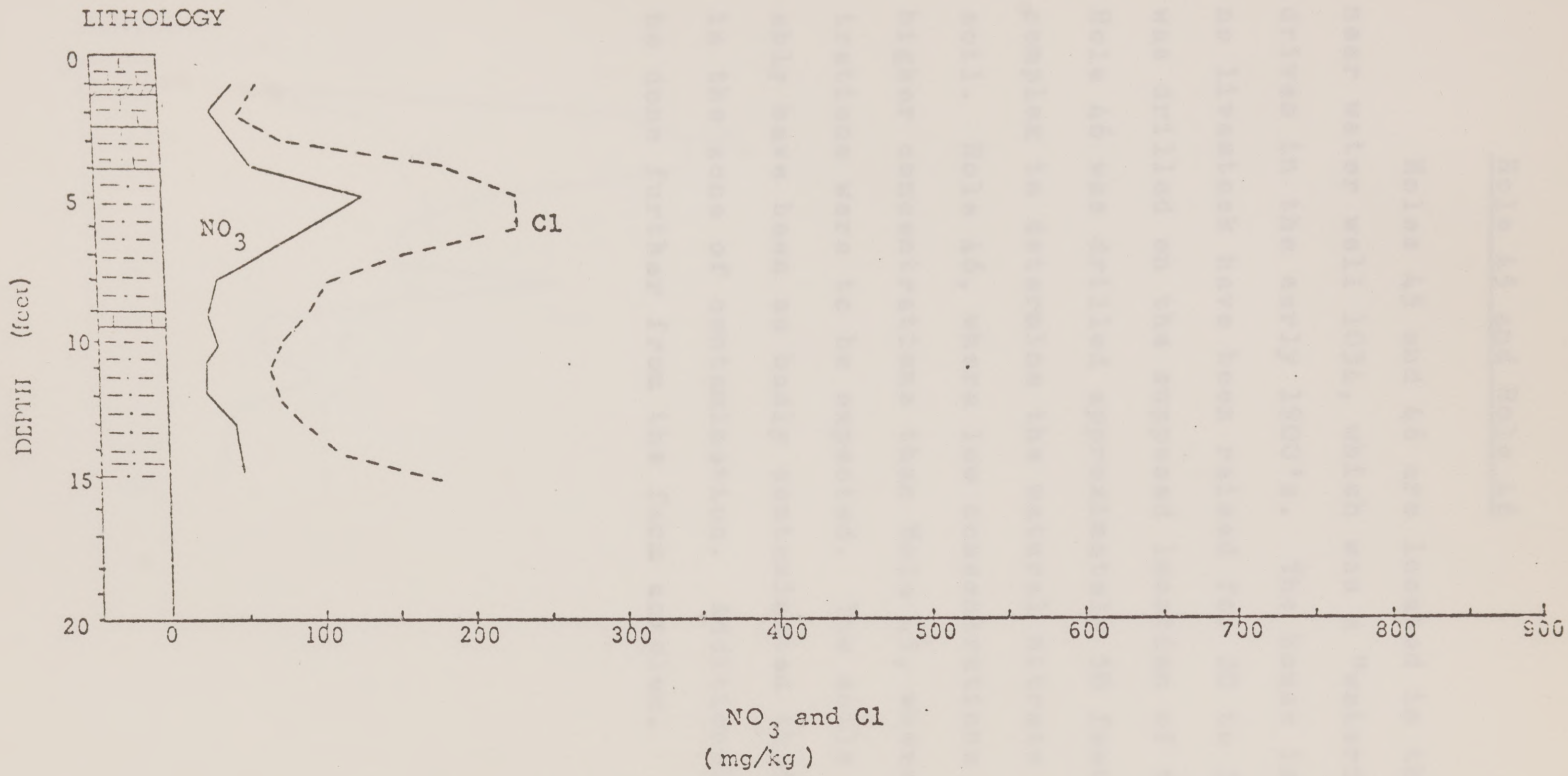
Hole 41. Located on a manure pile in same barnyard as Hole 40.



Hole 42. Located on the old barn site in the same barnyard as in Hole 40.



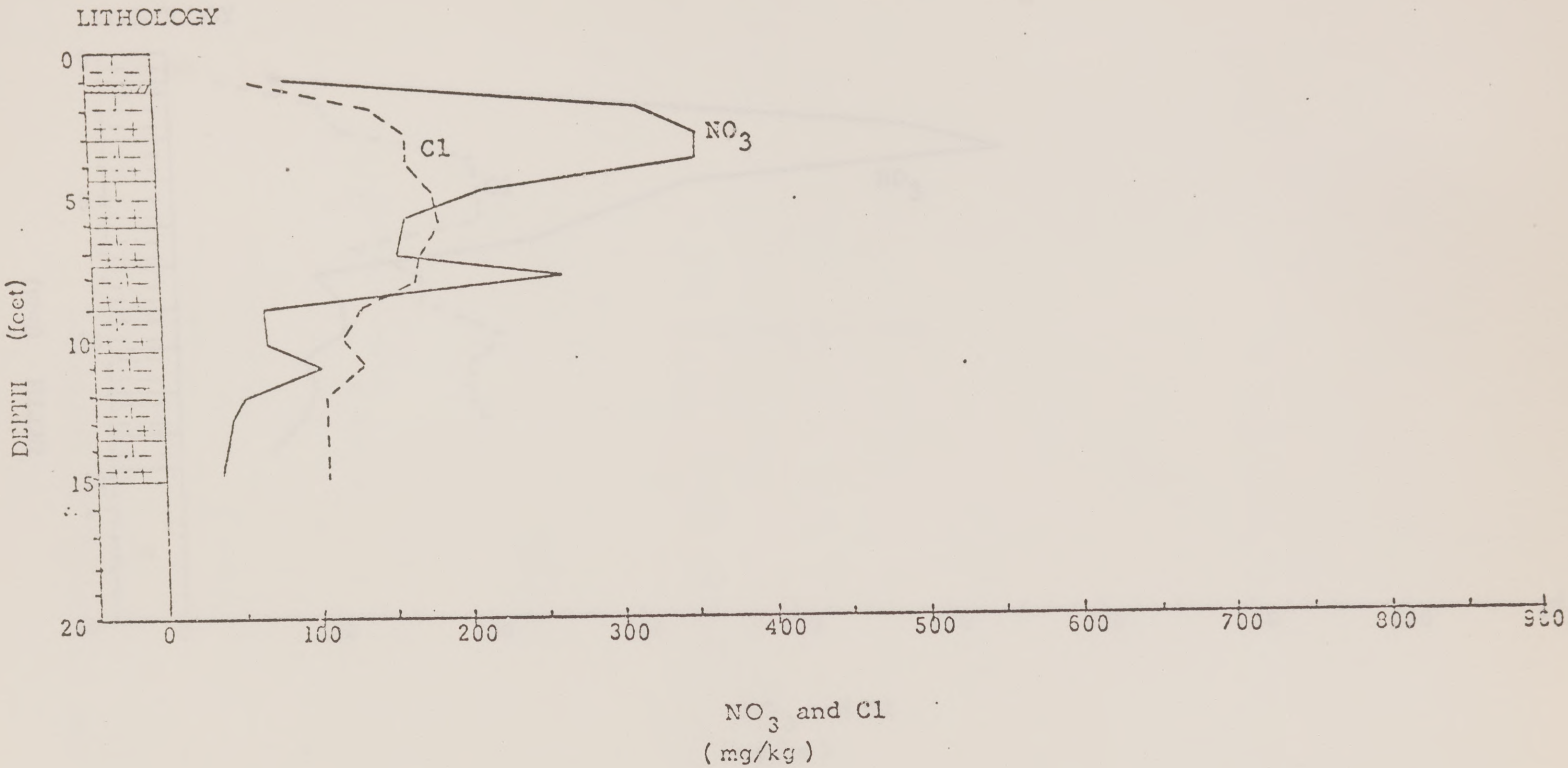
Hole 43. Located 5 feet outside the southwest corner of the same barnyard as in Hole 40.



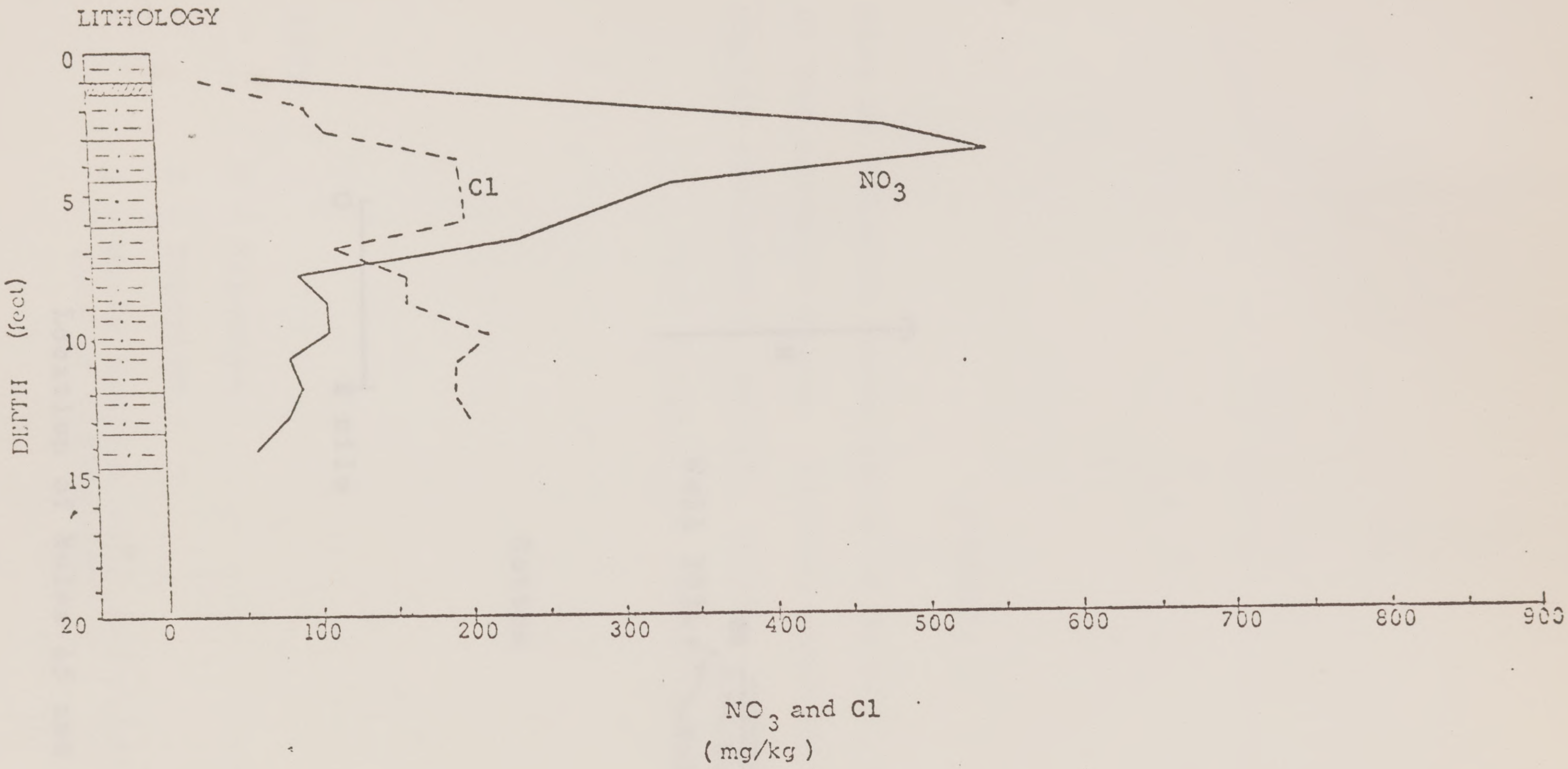
Hole 44. Located 10 feet north of a septic tank lateral, 40 feet south of the barnyard and 60 feet north of water well 551.

Hole 45 and Hole 46

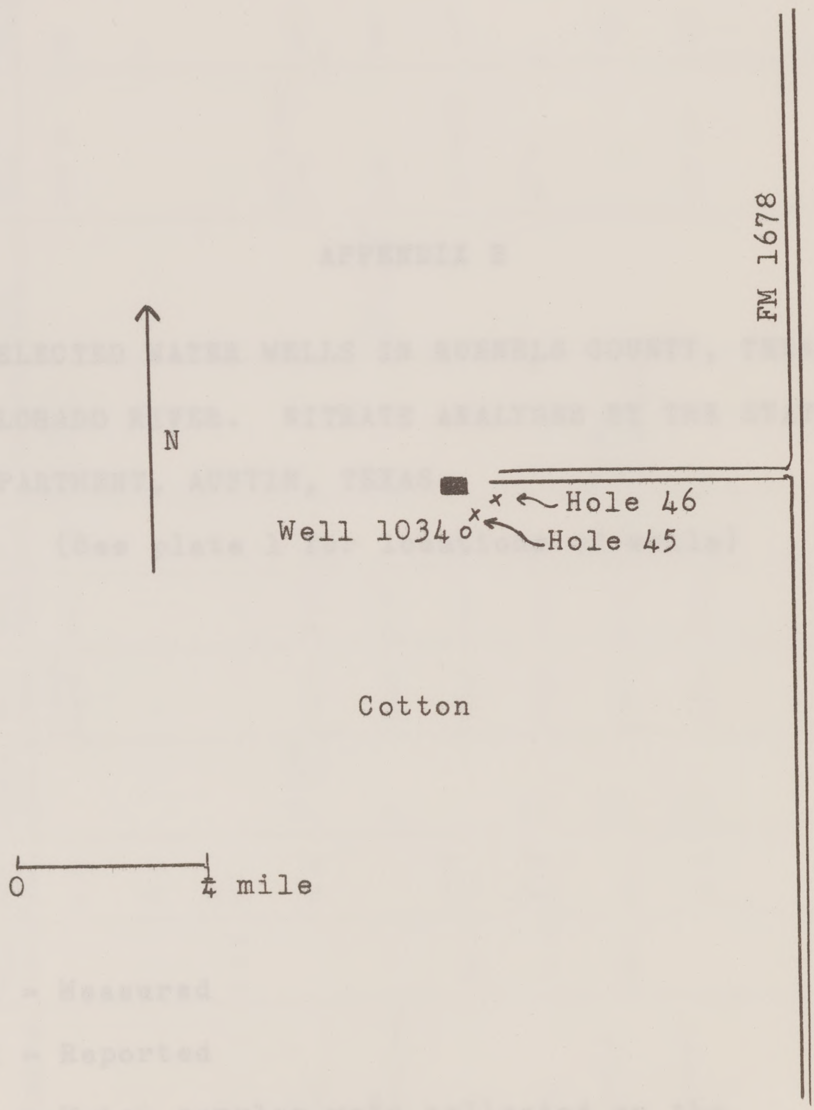
Holes 45 and 46 are located in the same farm complex near water well 1034, which was a "watering hole" for cattle drives in the early 1900's. The house is still occupied, but no livestock have been raised for 20 to 30 years. Hole 45 was drilled on the supposed location of the old water trough. Hole 46 was drilled approximately 50 feet away from the farm complex to determine the natural nitrate concentration in the soil. Hole 46, where low concentrations were expected, had higher concentrations than Hole 45, where the higher concentrations were to be expected. The soils in this area probably have been so badly contaminated that Hole 46 was still in the zone of contamination. Additional drilling needs to be done further from the farm complex.



Hole 45. Located on probable site of an old water trough for cattle and 10 feet south of water well 1034.



Hole 46. Located in cotton field and 40 feet east of house and water well 1034.



Location of Holes 45 and 46

APPENDIX B

DATA ON SELECTED WATER WELLS IN RUNNELS COUNTY, TEXAS, SOUTH OF THE COLORADO RIVER. NITRATE ANALYSES BY THE STATE PUBLIC HEALTH DEPARTMENT, AUSTIN, TEXAS.

(See plate 1 for locations of wells)

KEY:

M = Measured

R = Reported

1 = Water samples were collected on the date of visitation

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/l)	NO_3 (1970) (mg/l)	Comments
1	Emil Kloesil 2S Rowena		51 R		Plastic Cased	Elec.	New	Few cattle in fields		100Y SE	60	204	
2	Emil Kloesil 2S Rowena		37 R										
3	Emil Kloesil 2S Rowena	+.5 M	40-45R										
5	L. F. Loika 7MS Ballinger		60 R	60, seep at 45	Cased	Elec.	6 Yrs.			50' E Cess-pool	300	242	
6	C. Dankworth Rt.67, 2MS Ballinger			72	Cased	Elec.			Next to water trough	50'E	100	886	Over-flowing septic tank
8	C. Schaefer 2½ SW Rowena	6 M	29.6 M		Cased	Wind	Old			150 yds.N	370	357	
14	Ray Brown 1MS Ballinger	7½ M	82 or 90 R	28 50	Cased	Elec.				40' S			
15	Otto A. Steinback 4S Rowena	50? R	62 R	44 54	Cased	Wind	Old	Cattle, chicken in cattle yard			280	340	In the barnyard
16	Otto A. Steinback 4SRowena		62 R	44 54	Cased	Elec.				200' SW	220	250	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/l)	NO_3 (1970) (mg/l)	Comments
17	Alvin Halfman 4S Rowena W.		55 R		Cased	Elec.	New	Full Barn-yard	25'E	40'N	280	410	
18	Alvin Halfman 4S Rowena	27 M	55 M		Cased	Wind	Old		1'E of Barnyard		540	791	Right next to barnyard
26	Baker & Carwile 6S Ballinger		119 R	90	Cased	Wind	Old			¼ M E	65		
27	Leonard Luedtke 3M NE Miles		70-75 R		Cased	Wind	Old	A few sheep		250Y S	85	90	
33	Mrs. J. L. Kresta 1M N Bethel	35 R	125 R	90	Cased	Elec.		Pigs in the past	200Y W	½M W	185	220	
44	Alfon Book 2½M E Miles	16.5M	47 R	47	Cased	Wind	Old						
45	A. F. Book son 2M N Miles		70 R		Plastic Casing	Elec.	New	No evidence		200' W	16	20	
59	Mrs. Otto Halfman 9SE Rowena	28.6	50 M		Cased	Wind	Old			½M W 100 yds. E	340	420	Near deserted house
60	L. S. Cape 1M S Ballinger		27 R	18	Cased	Elec.	New	None		100' W	5		

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
65	Freddy Gallas 3SE Rowena		60 R	20' 55' Strong-est	Cased	Elec.	3 Yrs.			30' NW	135	184	
66	Freddy Gallas 3SE Rowena	7 M	60 M										
71	Erwin Halfman 5MSW Ballinger									60'N ?	205	142	
71	Erwin Halfman 5MSW Ballinger	17.5 M	22.6M		Dug								
74	Joe Hovarak River Road, S. Ballinger		40-50 R	40-50						100' SW	74		
75	Nobert Rohmfield 5S Ballinger	9 M	30 R	12-15 30	Cased	Elec.		Over 80 hd. cattle & sheep	70'S	20' Cess-pool	260	220	
76	Nobert Rohmfield 5S Ballinger							Over 80 hd. cattle & sheep	50'NW	70' Cesspool	140	150	Stock pond
98	Leoran Hoelscher 6S Ballinger	0 M	21 M	15	Plastic Casing	Elec.	New	25 young bulls at present	200'E 200'N		280	240	Well next to stock pond
105	W. V. Connelley River Road, S. Ballinger	4.5 M	13.1 M	13	Dug	Elec.	Old	Very few		200 Y N up the hill	56	<.4	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
112	R. Bruchmiller 9MS Ballinger	37 M	90 M		Tin Casing	Wind	Old	Pigs and chickens	10'	40'N	48	280	1st NO_3 test showed 3680 mg/1
113	R. Bruchmiller 9MS Ballinger	1.5 M	12 M	≈12	Cased	Wind	New			¼M E farm		419	
114	R. Bruchmiller 9MS Ballinger	60.5 M			Cased	Wind	Old ?	None		Deserted farm ¼MW		8.5	
114a	R. Bruchmiller 9MS Ballinger	42.6 M	95 M		Cased		Old			20'W of house			
115	R. Bruchmiller 9MS Ballinger	32.7 M	65 M	62	Cased	Wind	Old	None Apparent		100'N	120	29	
116	R. Bruchmiller 9MS Ballinger	14.2 M	60 M	37	Cased	Wind	Old	20 cattle in the pen		¼MN	320	312	
117	Vernon Glass 1MN Lowake		60-65 R		Cased	Wind	Old	Cattle and hogs	150'E	100'E	145	110	
118	George Schaefer 1MW Martins Inn		60 R		Cased	Elec.				40'S	420	250	House well
119	George Schaefer 1MW Martins Inn	19 M	73 M		Cased	Elec.	New			250Y E		344	Irrigation well

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Livestock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/l)	NO_3 (1970) (mg/l)	Comments
125	A. C. Wendland 4M W Miles		92R						100' NW		32	36	House well
126	Gus Klaus 9 SW Ballinger	8.5M	16.3M	16	Dug	Elec.		Cattle	200' W	200' W	370	311	
132	A. W. Strube 1M E Rowena		100R		Cased	Wind	Old	50 sheep, 50 cattle, 50 hogs	1/3M E	1/3M E	230		
141	Roudie Hohensee 4M N Miles		70-80 R		Tin Casing	Wind		Cattle	20' S	House 20' to the S	320	220	
147	Miss Agnes Hoelscher 3M E Rowena		40 R					A few	1/3M W	1/3M W	185	210	
148	Charles Hoelscher 3M E Rowena		60 R		Cased	Elec.				40' S	290	155	
157	L. Frenzel 2M S Rowena	11.6M	52.7M		Cased	Wind	Old 35	Used to keep cattle	150Y W	150Y W	260	540	
158	Harry Halfman S Olfen	27.8M	54.7M		Cased	Elec.		Cattle	30' N		340	405	
162	James Eggemeyer 1½M N Miles		119R	86	Cased	Wind				100Y E	26	3.0	
164	Paul Luedtke 3NW Lowake		75 R	33				Few cattle		200Y S	95	80	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
177	Alex Schwertner 1S Ballinger		38R		Cased	Elec.	New	Chickens	300Y W	60' SE	36	34	
200	Arthur Eggemeyer 4½M SE Miles	47R	66R	35 57	Plastic Casing	Elec.	New		100'N	200'	85 another well	65	New well with packers above producing hori-zon
201	Herbert Book 1M NW Lowake		45+R	45	Cased	Elec.			Barn 50'N	50' W	130	220	
202	Herbert Book S of Schwertner's	0 M	20M		Dug	Wind	Old	Cattle & Sheep	¼M W		12	90	Dug well next to stock tank
204	Werner Niehaus 6M S Ballinger	0 M	30M	19	Cased	Wind	Old	Cattle	1000' N	1000' N 500' E	350	378	
205	Werner Niehaus 6M S Ballinger	1.5M	45M	19 41	Plastic Cased		New			30'S of Well #204		284	
210	Vernen Wallace S Ballinger	9	28		Dug	Elec.				90' S 70' S	105	95	Well dug in gravels
221	Robert Lee Jones S Ballinger			65R						75' SW	1		
229	Walter O. Lange, Jr. 9 S Ballinger		32R		Cased	Elec.				25'	240	357	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
228	Walter O. Lange, Jr. 9 S Ballinger	16.8 M	60 M	30' 60'	Dug	Wind	Old			150'N	380	290	
230	Walter O. Lange, Jr. 9 S Ballinger		70'R		Cased	Elec.	New			¼M N	450		
231	Mrs. John Simecek 5M SW Rowena		45'R		Dug	Elec.					170	160	
223	Walter Lange, Sr. 9 S Ballinger		31'R		Cased	Elec.	Old			25'N Cess-pool	410	456	
232	Walter Lange, Sr. 9 S Ballinger	14.29M	28.6M	25-28	Dug	Wind	Old	Manure around wells					
233	W. Beimer 10 W Ballinger	14.31M	29.16M	25-28	Cased	Wind	Old 50yrs	A few cattle	40'S	30'N	600	572	
234	W. Beimer 10 W Ballinger	12.16M	17.7M	14-18	Dug	Elec.	20yrs	A few cattle	80'SW	50'NW	390	378	
251	P. J. Block N of Olfen	7.25M	33 M		Cased	Wind	Old	Very few, neighbors some chick-ens		1500'N 200' W	500	410	
273	W. H. Namkin 7½ SE Rowena		61 R		Cased	Wind	Old			75'S	48	294	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
279	A. W. Hoelscher 6M SW Ballinger	1 M	18 M	12'	Dug	Wind	Old	Cattle & hogs	300 Y NW hog pen		440	351	
286	Arnold Schraer 1N Lowake	20-25R	55R		Cased	Wind	100yr	Cattle & hogs	100'SW	70'N	155	180	
313	Paul Halfman 11 SW Ballinger	6 M	34 M	10' 25'	Dug	Elec.	Old			10'N	660	777	Dug well by the septic tank
314	Paul Halfman 11 SW Ballinger	5.0 M	37.15M		Cased	Wind	Old	Few cattle		200Y N		179	Windmill in field
316	Gladys Davis 6 S Ballinger	5.91 M	40-45R		Plastic Casing	Elec.	Re-cased re-cently		½MW of hog pens	50'S	440	420	
319	C. A. Cram Rt. 67, 2M S Ballinger	10 M	17 M	15-17	Dug	Wind	Old	Raised cattle all his life		50' and 60'	104	50	
324	Frank J. Gulley 2M E Rowena	44.5M	62 M		Cased	Elec.	New pump and casing		In the mid-dle of the farm yard	50' E	210	260	
325	Frank J. Gulley 2M E Rowena	35 M	80 M		Cased	Wind	Old	Always had a few					

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
362	Clarence Henning 2M S Rowena	10.3M	70 M		Cased	Wind	Old	Cattle & hogs	40'S	40'E	700	560	
365	E. L. Kvapil 1M E Miles		75 R	75	Cased	Elec.		Many chickens	100'S	50'SE	70	64	House well
366	E. L. Kvapil 1M E Miles		75 R	75	Cased	Wind	Old		30'E	150'N	62	56	Windmill
367	E. L. Kvapil 1M E Miles		75 R	75	Plastic Casing	Elec.	New	None around		100'N	58	95	Son's well
368	B. Ransbarger 17M SE Ballinger	24 M	74 M		Cased	Elec.	Old	Few cattle and sheep	150'SE	100'E	115	150	House well
369	B. Ransbarger 17M SE Ballinger	22 M	52 M		Cased	Wind	20y±	Cattle and sheep	20'N	½MW	380	326	
379	Daniel Redman 4M W Rowena		100 R		Cased	Wind	Old			200'W	205	225	
385	Ben Willberg 3M SE Rowena	≈45 R	85 R	60'	Cased	Wind		Few cattle		100'W	215	130	
386	E. O. Eggemeyer 9M S Ballinger	20.75 M	43 M		Cased	Elec.				200 Y SE of house	310	315	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Livestock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
388	Emit O. Eggemeyer 9M S Ballinger	6.95M	80M		Cased	Wind	Old	Hogs and cattle	0' next to hogs	25'W		1428	Well next to hog pen. A few cattle died from the well water.
393	David Ocker 4M S Ballinger	27 M	37 M		Dug	Elec.	Old	None near the house		30'N	170	168	
394	Charles Ocker 4M S Ballinger	25.5M	47 M		Cased	Wind	Old	Right in the middle of corral				216	Well located in corral.
395	Ray Holtman 4M SW Ballinger		60'R		Cased	Wind		Cattle		200 Y N	340		
415	Lee Roy Pelzrl 1½M N Miles		105R		Cased	Elec.	Old	None on sight		70'SW	4	1.5	
418	J. Busenlehner 12S Ballinger		40 R	28	Cased	Elec.	New			½M W House	230	190	Irrigation well
419	J. Busenlehner 12S Ballinger		60'R	35'	Cased	Elec.	New	Many cattle	200' S of pens	30'W	250	240	House well
420	J. Busenlehner 12S Ballinger	13.6M	18'M		Plastic casing		New						Unused well

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/l)	NO_3 (1970) (mg/l)	Comments
434	Ed Moonen 1M S Ballinger, Rt83		34 R		Cased	Elec.	New	Cattle	½M N	½M N	35	12	by Colorado River
447	Hilmer Schaefer 2SE Rowena	25 M	63 R	50-55	Cased	Elec.	10yrs	Cattle	200' E	200' E	240	260	
463	A. J. Glass SE Miles		90 R		Cased	Wind	Old	6/yr cattle	3'	30' N	255	120	
464	Victor Schwertner 9 SW Ballinger		30 R	30	Cased	Elec.		Many cattle		200Y S	300	326	
469	Harvey Gulley ½M E Rowena		110 R	45	Cased	Elec.		No cattle near		200Y E	155	288	
471	Tocho Alverdo in Rowena		40 R		Cased	Wind	Old	Few chickens		30' S of house	50	80	
473	Arnold Fuchs 9 SW Ballinger		55 R	48	Plastic	Elec.	New	Cattle	15'S	200' W	860	336	Producing well
	Arnold Fuchs 9SW Ballinger	10.3M	35 M		Cased	Wind broken	Old	Rignt next to cattle pen		200' W			Deserted wind-mill
	Arnold Fuchs 9SW Ballinger		31 R	27	Caved in								Caved in well

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/l)	NO_3 (1970) (mg/l)	Comments
484	Joe T. Haechten 9½S Ballinger		90'R	47'	Cased	Wind		Cattle & Chickens	¼M W	¼MW	350	336	
493	Mrs. C. H. Midgley South Ballinger	30 M	30'M		Dug	Wind	Old	Pigs, Cattle & Chickens	200'N	100'NW	300	200	
494	W. J. Kahlig 9 S Ballinger	4'M	33.6M		Cased					50'E	810	809	
495	W. J. Kahlig 9 S Ballinger		65'R		Cased	Wind	Very Old	None at present		100Y E		1365	
496	Arnold Holubec 4 SE Rowena	31.6M	60'M	50'	Cased	Elec.	New	100 cattle/year in the past		100'E	145	130	
506	Ben Wilde at Bethel		72'R	72'	Cased	Elec.	New		200Y W	200Y W	190	221	
512	Ralph Lange Martin's Inn Rd.		41'		Cased	Wind	Old 1920's			200'S	660	270	
513	William Urbanek 4S Rowena		65 R	65	Cased	Elec.		Few cattle		200Y S	112	130	South well
516	William Urbanek 4S Rowena		65 R	65	Cased	Elec.				180Y S	120	110	East well
517	William Urbanek 4S Rowena									¼ME		94	Seep water

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
547	Ben Wilde Bethel		110 R		Cased	Wind	Old		5'		300	299	
551	Paul Pieper 1M N Rowena	56 M	75 M	75'	Cased	Elec.			100'S	100'S cesspool	200	294	Irrigation well at house
552	Paul Pieper 1M N Rowena	28'M	70.2M	25' 68'	Plastic Casing		New						New well
553	Harvey Gulley 4 W Rowena	4.3 M	14.5M		Cased	Wind	Old	No evidence of cattle		200Y S	290	290	
578	Charlie Matschek 3½N Rowena	20'R	25-30R	18-20'	Cased	Elec.		Cattle in the past			18	10	In gravels
599	Miles Coop Gin Miles, Texas		50 R		Cased	Elec.				100' N of Gin	175	180	
600	Alfon Book 2M E Miles at P. Frenzels		47'R	47'	Cased	Elec.				200'S	185	190	
626	Forrest Pohler 2N Rowena		65 R		Cased	Elec.					175	210	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
627	W. Wehlman 3 N Rowena	9.8M	35M		Cased	Elec.		Cattle	0	200'E	10	<.4	Limestone aquifer overlain by gravels
630	Roman Molter 7 SW Ballinger		49'R	39	Cased	Wind	Old 1921	30 Cattle	¼M W	¼M W	220	270	
670	P. Frenzel 2M E Miles		100'R	68	Cased	Elec.				100'SE	200	270	
671	Paul Frenzel 2M E Miles	26.5M	47.5M		Cased	Wind			Dairy farm 300Y S	200'S	170	180	
672	George Ruppert Rowena		80 R	68	Cased	Elec.	5yr +			40' W Cess-pool	330	1302	
711	Jack King ½ W Rowena		45 R	25'	Cased	Elec.	New	None		30' + 100SE	310	378	
727	James Teplicek ½M S Rowena Farmyard		60-70R		Cased	Elec.		50 pigs	5'E			1620	Well located down-slope from hog pens
728	James Teplicek ½M S Rowena	6	54 M		Cased	Elec.				100Y S		130	Irrigation well
747	Edwin Urban 3 NW Miles		70-80R	60'	Cased	Elec.	Old	None apparent		100' NW	132	170	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/l)	NO_3 (1970) (mg/l)	Comments
784	Andrew Lange 1M E Rowena		100 R		Cased	Elec.	1954	Few cattle	½M E	½M E	170	300	
864	W. H. Dierschke 2M NE Rowena	26.6M	100'R		Cased	Elec.		None in nearly ½M		½M W of house	240	210	
865	Omar Halfman 8M S Ballinger	6.6M	20'M		Dug	Elec.			50'NE	25'W		1250	Dug well by the house
866	Omar Halfman 8M S Ballinger	3.6M	30 M		Dug	Elec.		None around				200	Olfen church well
867	Omar Halfman 8M S Ballinger	6 M	60'M		Cased	Wind	Old	Cattle	0	50'SW		1898	Windmill in corral
868	Omar Halfman 8M S Ballinger	6.17M	61'M		Cased				½M SW	½M SW		920	Location of TWDB water level recorder
869	Omar Halfman 8M S Ballinger	.5'M	25 R								290	243	Olfen school well
870	A. C. Wendland 4M W Miles		≈90 R		Cased	Wind		50 cattle 100 sheep	0		310	110	Well located next to small feedlot
1000	Smithwick in Miles		80'R	50-60'	Case gravel packed	Wind			200'S	400'S		120	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
1001	J. Hohensee 2M SE Miles		49 R		Dug		Old					190	Dug drainage well; interbedded lime-stone & marls
1002	Robert Schwertner 1M SW Rowena	4 M	20' M	18-20	Cased	Wind				200'S		280	
1003	E. R. Holubec 4 SE Rowena		70 R	63			New	No cattle now		150'S		820	
1004	Werner Lange Rowena		115' R	76	Cased	Elec.						360	
1005	Lyle & Lyle 2M S Ballinger	16.7M	42 M		Dug		Old						
1006	H. H. Gulley 2½M S Ballinger	22 M	60 M		Cased	None	Old	Cattle? De-serted pens	3'S	50'S		1470	Location of TWDB water level recor-der. A few cattle died at this well
1007	H. H. Gulley 2½M S Ballinger	1.7 M	30 M	15	Cased	Elec.	4 yrs	Some cattle	¼M E	¼M E			
1008	J. Hohensee 2M E Miles	60 R	100R		Cased	Elec.	Old			300'N		59	

Well No.	Name and Location	Depth to Water Table (ft)	Total Depth of Well (ft)	Depth to Water Strata (ft)	Well Type	Pump Type	Age of Well	Livestock	Distance & Direction from Live-stock	Distance & Direction from Septic Tank	NO_3 (1969) (mg/1)	NO_3 (1970) (mg/1)	Comments
1009	Arthur Halfman 1½M NW Lowake	25-30 R	45 R	45	Cased	Elec.		Few hogs & chickens		50'E		112	
1010	Cmereck 1½M N Miles		67-70R	67-70	Cased	Elec.	10yrs			50'		110	
1031	Ludwig Schwertner 1½NE Rowena	25M	70 M		Cased	Wind							
1032	Joe Pfluger 3M SW Ballinger		40'R		Cased	Elec.	New			250'N		25	
1033	Gus Frey 2M S Ballinger		60'R		Cased	Elec.				100'N			No sample; broken pump; few cattle died from water
1034	Frieda Backhous 5S Rowena		60'R		Cased	Wind	Very old	Cattle past	5'N	50'SW	2240	2162	Highest NO_3 in county; no obvious source of NO_3

APPENDIX C

CHEMICAL ANALYSES OF WATER FROM SELECTED WELLS IN RUNNELS COUNTY, TEXAS, SOUTH OF THE COLORADO RIVER. ANALYSES BY THE STATE PUBLIC HEALTH DEPARTMENT, AUSTIN, TEXAS.

1969 PARTIAL CHEMICAL ANALYSES BY TEXAS A AND M EXTENSION LABORATORY IN LUBBOCK, TEXAS. SAMPLES WERE COLLECTED DURING THE SUMMER OF 1969 BY THE OWNERS.

(See plate 1 for well locations)

KEY:

I.S. = Insufficient Sample

S.N.T. = Sample Not Taken

Well No.	Name	Date	NO_3 (1969) mg/1	NO_3 (1970) mg/1	TDS (1969) mg/1	TDS (1970) mg/1	SiO_2 mg/1	Ca mg/1	Mg mg/1	Na mg/1	HCO_3 mg/1	SO_4 mg/1	Cl mg/1	F mg/1
1	Emil Kloesil	7-08-70	60	204	2,400	3,630	16	660	175	223	234	1,810	420	3.5
5	L. F. Loika	6-12-70	300	242	1,470	1,590	22	265	33	230	296	210	443	.8
8	C. Schaefer	6-23-70	370	357	1,908	2,150	19	216	118	328	276	472	497	4.5
15	O. Steinback	7-08-70	280	340	3,000	2,080	22	211	109	339	257	387	630	2.6
16	O. Steinback	7-08-70	220	250	1,650	2,030	23	274	155	185	220	274	670	1.9
17	Alvin Halfman	6-23-70	280	410	1,680	1,730	24	232	89	197	343	216	388	1.7
18	Alvin Halfman	6-23-70	540	791	1,800	2,390	27	417	89	192	326	202	510	1.2
27	L. Luedtke	7-17-70	85	90	1,020	1,140	23	131	72	164	250	145	387	1.2
33	Mrs. J. Kresta	7-17-70	185	220	1,800	2,110	29	307	45	354	290	422	590	1.9
45	A. Book	7-16-70	16	20	1,140	1,070	16	121	86	150	316	113	405	2.2
59	Mrs. Otto Halfman	6-27-70	340	420	1,680	1,870	19	210	91	270	282	256	458	2.2
65	F. Gallas	7-07-70	135	184	1,560	1,370	20	173	120	121	326	203	386	1.7
75	N. Romfield	7-19-70	260	220	1,320	1,840	29	269	30	317	244	367	484	1.9
76	N. Romfield	7-19-70	140	150	1,680	1,100	20	88	43	225	151	211	284	1.9
98	L. Hoelscher	7-19-70	280	240	1,560	1,750	27	168	83	291	298	286	486	4.1
105	W. V. Connelley	1970	56	<.4	960	760	27	102	60	81	362	164	145	.8
112	R. Bruchmiller	7-20-70	48	280	1,920	3,510	22	740	78	233	281	1,630	383	1.3
113	R. Bruchmiller	6-15-70		419		1,170	17	211	18	129	201	113	163	1.4
114	R. Bruchmiller	6-15-70		8.5		870	22	179	26	94	383	186	160	.8
112	R. Bruchmiller	6-15-70		3,584		8,100	24	1,390	226	590	244	1,300	840	2.5

Well No.	Name	Date	NO_3 (1969) mg/1	NO_3 (1970) mg/1	TDS (1969) mg/1	TDS (1970) mg/1	SiO_2 mg/1	Ca mg/1	Mg mg/1	Na mg/1	HCO_3 mg/1	SO_4 mg/1	Cl mg/1	F mg/1
115	R. Bruchmiller	6-15-70	120	29	1,680	2,660	19	690	27	129	294	1,340	279	1.8
116	R. Bruchmiller	6-15-70	320	312	1,800	1,940	24	336	27	265	250	237	610	1.6
117	V. Glass	7-15-70	145	110	1,200	1,210	25	155	64	175	254	178	373	1.8
118	G. Schaefer	7-20-70	420	250	1,860	2,170	26	333	86	297	174	253	840	2.1
119	G. Schaefer	7-20-70		344		2,210	29	276	87	328	337	493	481	2.1
125	A. Wendland	7-19-70	32	36	510	500	24	72	42	50	325	30	87	1.2
126	G. Klaus	6-23-70	370	310	1,080	1,110	33	131	38	163	217	147	177	2.5
141	R. Hohensee	7-17-70	320	220	900	940	22	163	36	97	294	103	156	.8
147	Miss Agnes Hoelscher	7-07-70	185	210	1,800	2,040	21	232	134	273	237	358	700	.9
148	C. Hoelscher	1970	290	155	1,260	1,190	22	168	90	97	365	252	225	1.1
157	L. Frenzel	7-08-70	260	540	1,800	3,611	23	443	194	493	329	680	1,070	2.4
158	H. Halfman	6-24-70	340	405	1,560	2,140	22	266	111	302	338	245	620	1.7
164	P. Luedtke	7-15-70	95	80	1,140	1,190	.25	161	71	158	270	126	432	1.3
177	A. Schwertner	7-22-70	.36	34	660	750	34	89	42	113	423	139	87	1.9
162	J. Eggemeyer	7-16-70	26	3	1,080	1,780	20	211	103	213	266	980	120	1.9
201	H. Book	7-14-70	130	221	1,200	4,320	15	620	231	444	244	1,940	730	4.0
202	H. Book	7-14-70	12	90	264	1,320	24	175	67	195	264	205	429	1.7
204	W. Niehaus	6-14-70	350	378		2,300	16	252	134	348	234	458	690	2.8
205	W. Niehaus	6-14-70		284	2,400	2,380	19	193	159	399	287	331	750	4.8
210	V. Wallace	7-21-70	105	95	1,080	1,350	38	143	92	178	487	390	178	1.2

Well No.	Name	Date	NO_3 (1969) mg/1	NO_3 (1970) mg/1	TDS (1969) mg/1	TDS (1970) mg/1	SiO_2 mg/1	Ca mg/1	Mg mg/1	Na mg/1	HCO_3 mg/1	SO_4 mg/1	Cl mg/1	F mg/1
210	V. Wallace	7-28-70		110	1,350	1,350	37	138	100	181	487	369	178	1.2
228	W. Lange, Jr.	6-18-70	380	290	1,260	1,530	18	174	36	284	298	279	298	2.5
229	W. Lange, Jr.	6-18-70	240	357	1,260	1,330	20	187	30	202	287	184	202	2.3
230	W. Lange, Jr.	6-18-70	450	520	1,020		20	176	29	162	232	139	115	2.8
231	Mrs. J. Simicek	7-14-70	170	160	1,440	1,880	24	207	76	326	256	432	520	3.0
232	W. Lange	6-18-70	410	456	1,500	1,570	21	182	89	198	368	101	335	1.6
233	W. Beimer	6-23-70	600	572	1,380	1,560	35	142	57	286	279	241	279	3.1
234	W. Beimer	6-23-70	390	387	1,680	1,980	36	197	65	343	277	299	333	3.0
251	P. J. Block	6-13-70	500	410	960	930	23	127	20	109	85	124	69	3.3
273	W. A. Namkin	6-22-70	48	294	1,680	2,470	19	389	115	283	281	471	760	1.8
279	A. W. Hoelscher	6-11-70	440	351	2,400	2,410	20	268	135	355	323	328	790	2.8
286	A. Schraer	7-15-70	155	100	1,320	1,490	23	163	78	235	265	287	395	1.9
200	A. Eggemeyer	7-15-70	85	65	900	1,150	24	171	71	137	290	120	415	1.5
313	P. Halfman	6-24-70	660	777	2,880	3,710	25	500	162	486	227	373	1,270	3.3
314	P. Halfman	6-24-70		179		2,180	24	251	98	386	259	314	800	3.0
316	Gladys Davis	6-11-70	440	420	2,700	2,740	25	274	138	465	267	443	840	3.7
319	C. A. Gram	7-09-70	104	50	1,200	1,110	39	110	50	211	467	216	198	2.1
324	F. J. Gulley	7-07-70	210	260	1,920	2,570	16	443	127	211	226	880	520	1.0
362	C. Henning	6-22-70	700	560	2,400	2,220	24	330	107	237	282	189	630	2.5
365	E. Kvapil	7-17-70	70	64	660	610	21	73	37	86	244	78	129	1.1

Well No.	Name	Date	NO_3 (1969) mg/1	NO_3 (1970) mg/1	TDS (1969) mg/1	TDS (1970) mg/1	SiO_2 mg/1	Ca mg/1	Mg mg/1	Na mg/1	HCO_3 mg/1	SO_4 mg/1	Cl mg/1	F mg/1
366	E. Kvapil	7-17-70	62	56	600	560	21	60	33	89	254	72	106	1.1
367	E. Kvapil	7-17-70	58	95	960	1,130	28	156	72	139	288	139	360	1.0
368	B. Ransbarger	6-24-70	115	150	1,440	1,800	44	159	27	413	339	397	436	2.4
369	B. Ransbarger	6-24-70	380	326	1,080	1,440	26	288	15	165	179	71	463	.4
379	D. Redman	7-14-70	205	225	900	960	23	83	27	191	259	165	115	3.2
385	B. Willberg	7-19-70	215	130	1,920	2,040	24	280	36	345	267	328	590	1.9
386	E. O. Eggemeyer	6-19-70	310	315	2,880	3,180	18	307	196	483	339	720	970	2.3
388	E. O. Eggemeyer	6-19-70	1,230	1,428		8,150	25	830	432	1,270	270	1,540	2,490	2.9
393	D. Ocker	7-09-70	170	168	1,680	1,310	20	180	62	173	268	274	296	.7
394	C. Ocker	7-09-70		216		2,120	23	233	109	350	249	351	710	.9
415	L. R. Pelzrl	7-17-70	4	1.5	1,200	1,630	16	182	118	245	243	239	690	2.5
418	J. Busenlehner	7-18-70	230	190	1,080	1,140	20	207	24	138	232	131	265	.8
419	J. Busenlehner	7-18-70	250	240	780	880	21	177	20	87	226	86	189	.7
434	E. Moonen	7-19-70	35	12	2,700	3,600	36	229	240	660	600	1,340	780	3.1
447	H. Schaefer	7-08-70	240	260	2,040	2,240	20	330	140	240	223	312	820	1.9
463	A. J. Glass	7-15-70	225	120	1,680	1,410	24	159	94	205	333	184	465	1.7
464	V. Schwertner	6-23-70	300	326	1,320	1,590	28	173	67	254	172	248	405	2.8
469	Harvey Gulley	7-19-70	155	288	2,400	1,460	23	165	45	262	282	259	278	4.7
471	T. Alverdo	7-14-70	50	80	2,700	3,460	18	530	220	286	273	1,670	520	2.3
473	A. Fuchs	6-19-70	860	336	2,040	2,470	24	354	93	304	196	920	344	3.3
484	J. Haechten	6-19-70	350	336	1,680	1,620	22	236	67	193	210	249	410	2.5

Well No.	Name	Date	NO_3 (1969) mg/l	NO_3 (1970) mg/l	TDS (1969) mg/l	TDS (1970) mg/l	SiO_2 mg/l	Ca mg/l	Mg mg/l	Na mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	F mg/l
493	Mrs. C. H. Midgley	7-1970	300	200	2,280	2,260	24	234	148	317	439	680	439	2.1
494	W. J. Kahlig	6-12-70	810	809	3,600	6,120	19	650	309	970	287	1,060	2,070	3.3
495	W. J. Kahlig	6-12-70		1,365		4,970	19	670	226	580	259	690	1,290	2.5
496	A. Holubec	7-07-70	145	130	1,860	1,780	27	261	80	234	257	404	520	2.3
506	B. Wilde	6-12-70	190	221	1,260	1,370	18	226	41	179	288	198	343	.9
512	R. Lange	6-20-70	660	270	3,000	1,780	24	177	86	305	303	287	475	1.9
513	W. Urbanek	7-70	112	130	1,320	1,660	22	221	72	255	240	254	580	2.7
516	W. Urbanek	7-70	120	110	1,440	1,480	24	197	88	190	271	249	487	2.6
517	W. Urbanek	7-70		94		1,920	17	218	81	336	32	401	750	2.3
551	P. Pieper	6-23-70	300	294	2,160	3,000	19	433	188	258	279	1,190	481	2.3
552	P. Pieper *Epm	7-70					*	32.3	9.5	15.1	3.4	7.2	15.4	
553	Harvey Gulley	7-14-70	290	290	960	3,280	14	570	182	213	272	1,370	510	2.1
578	C. Matschek	7-27-70	18	10	4,320	7,000	18	1,010	322	1,020	300	1,390	3,100	1.0
599	Miles Co-op Gin	7-70	175	180	1,140	1,230	21	133	68	202	311	111	355	3.2
600	A. Book	7-16-70	185	190	1,020	990	27	126	48	132	312	91	221	1.0
626	F. Pohler	7-27-70	175	210	1,440	1,690	17	183	154	176	282	260	550	1.8
627	W. Wehlman	7-28-70	10	<.4	1,680	2,610	20	413	198	123	310	1,470	230	2.2
630	R. Multer	7-07-70	220	270	1,260	2,010	20	215	125	291	267	312	640	.8
670	P. Frenzel	7-15-70	200	270	1,020	1,490	23	196	85	196	354	103	440	1.0
671	P. Frenzel	7-15-70	170	180	900	1,150	27	179	64	131	312	60	356	.8

Well No.	Name	Date	NO_3 (1969) mg/l	NO_3 (1970) mg/l	TDS (1969) mg/l	TDS (1970) mg/l	SiO_2 mg/l	Ca mg/l	Mg mg/l	Na mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	F mg/l
672	G. Ruppert	6-23-70	330	1,302	900	1,800	18	590	156	348	338	550	680	2.4
711	J. King	6-23-70	310	378	1,800	2,570	19	275	149	375	232	452	800	3.5
727	J. Teplicek	7-15-70		1,620		5,400	20	850	325	333	354	1,080	980	2.9
727	J. Teplicek	7-28-70		1,260		4,870	24	740	308	348	339	1,030	990	3.5
728	J. Teplicek	7-23-70		130		2,640	24	385	190	193	253	1,160	428	2.7
747	E. Urban	7-07-70	132	170	900	820	21	98	55	100	337	70	137	1.4
784	A. Lange	7-70	170	300	2,010	2,380	21	336	178	223	227	326	880	.8
864	W. H. Dierscke	7-14-70	240	210	1,400	1,490	21	181	114	161	268	150	520	.9
865	O. Halfman	6-22-70		1,660		4,780	21	770	108	540	242	472	1,090	2.2
865	O. Halfman	7-28-70		1,250		3,880	22	610	104	470	238	387	920	2.5
866	O. Halfman	7-29-70		200		2,010	27	165	80	413	389	416	510	2.6
867	O. Halfman	6-22-70		1,898		5,350	22	780	238	490	282	570	1,210	2.5
868	O. Halfman	6-22-70		920		4,100	20	700	95	530	166	396	1,350	2.5
869	O. Halfman	6-22-70		290	1,260	1,500	24	190	48	250	253	241	379	1.3
870	A. C. Wendland	7-19-70	310	110	780	640	24	98	47	52	320	57	89	1.1
1000	Smithwick	7-17-70		120		910	27	118	57	118	334	83	217	2.4
1001	J. Hohensee	7-17-70		190		2,150	12	300	93	272	283	920	351	2.2
1002	R. Schwertner	7-08-70		280		2,190	17	245	73	389	220	520	560	3.4
1003	E. Holobec	7-07-70		820		2,950	29	476	81	357	229	330	740	2.7
1004	Werner Lange	7-70		360		3,790	18	600	202	359	245	1,250	880	2.1

Well No.	Name	Date	NO_3 (1969) mg/1	NO_3 (1970) mg/1	TDS (1969) mg/1	TDS (1970) mg/1	SiO_2 mg/1	Ca mg/1	Mg mg/1	Na mg/1	HCO_3 mg/1	SO_4 mg/1	Cl mg/1	F mg
1008	J. Hohensee	7-15-70		59		331	23	64	9	24	168	13	5	.3
1009	Arthur Halfman	7-15-70		112		1,350	25	175	65	205	265	208	430	1.8
1010	Cmereck	7-17-70		110		1,510	22	193	111	189	298	159	580	2.0
1032	J. Pfluger	7-27-70		25		3,130	18	620	118	235	285	1,380	590	1.0
1034	Mrs. F. Backhous	7-28-70	2,240	1,430	3,600	4,010	32	670	118	386	220	341	920	2.1
1034	Mrs. F. Backhous	6-22-70	2,240	2,162	3,600	4,980	30	840	142	412	198	328	970	2.3

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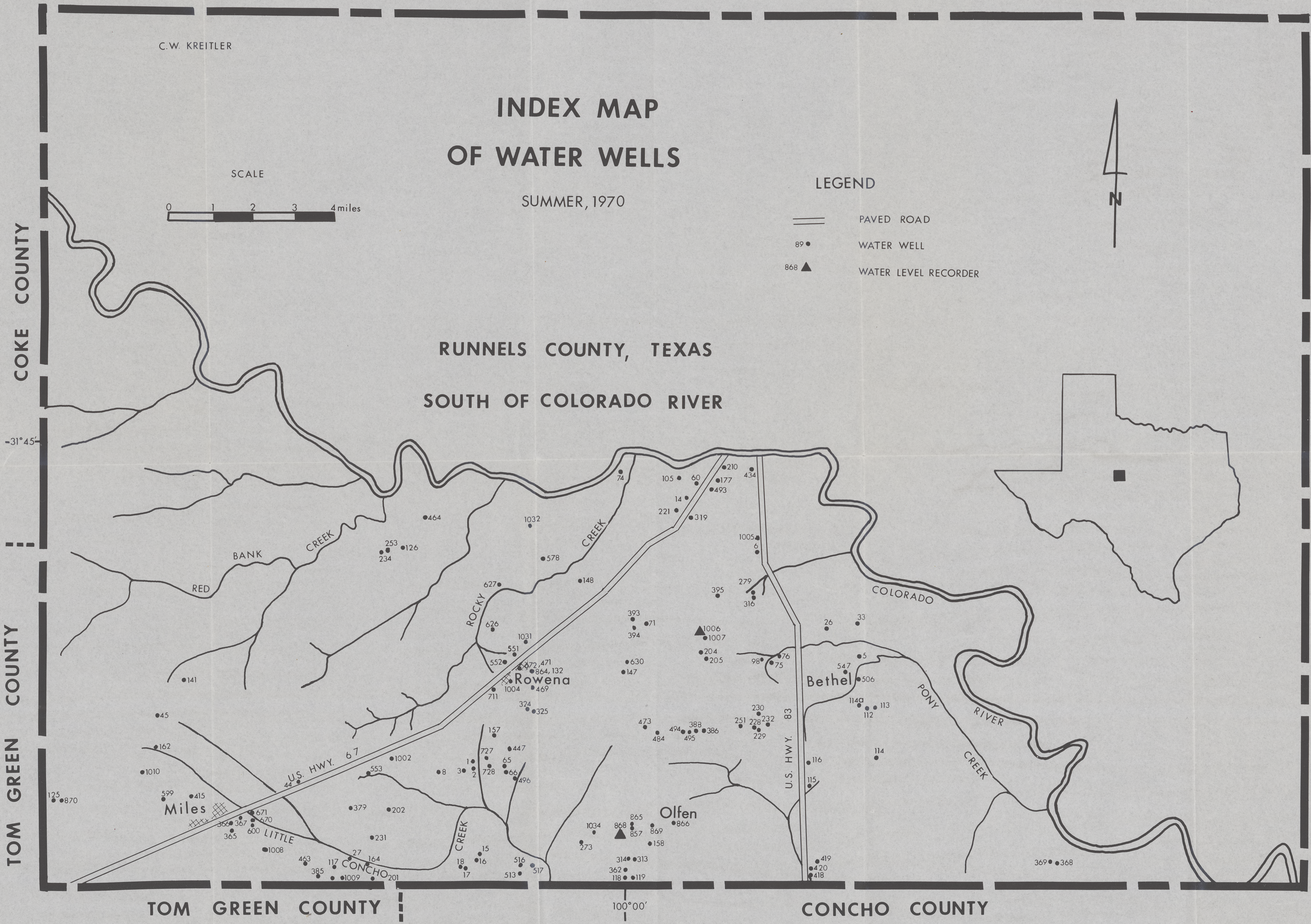
C.W. KREITLER
INDEX MAP
OF WATER WELLS
SUMMER, 1970
SCALE
0 1 2 3 4 miles
LEGEND
PAVED ROAD
89 WATER WELL
868 WATER LEVEL RECORDER
N
RUNNELS COUNTY, TEXAS
SOUTH OF COLORADO RIVER
COKE COUNTY
TOM GREEN COUNTY
TOM GREEN COUNTY
CONCHO COUNTY
31°45'
100°00'
RED BANK CREEK
ROCKY CREEK
COLORADO RIVER
PONY CREEK
LITTLE CONCHO
CREEK
U.S. HWY. 67
U.S. HWY. 83
Rowena
Bethel
Miles
Olfen